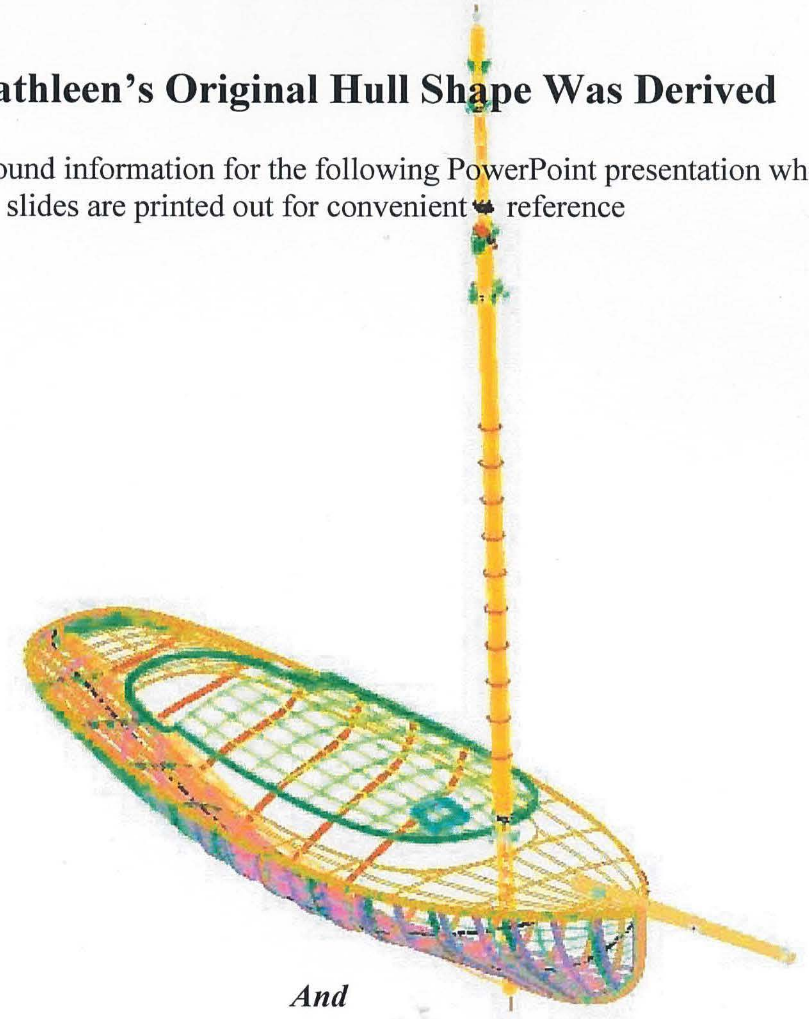
KATHLEEN

How Kathleen's Original Hull Shape Was Derived

Detailed background information for the following PowerPoint presentation whose slides are printed out for convenient reference



And

Restoring Kathleen: A Role for Digitally Assisted Reverse Perspective Analysis in 3D CAD

A PowerPoint presentation given at the 10th Maritime Heritage Conference Norfolk, Virginia, September 17-21, 2014 and again at the Museum Small Craft Association annual meeting, October 5-6, 2015 at the Chesapeake Bay Maritime Museum, St. Michaels, Maryland

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How *Kathleen*'s Original Hull Shape Was Derived

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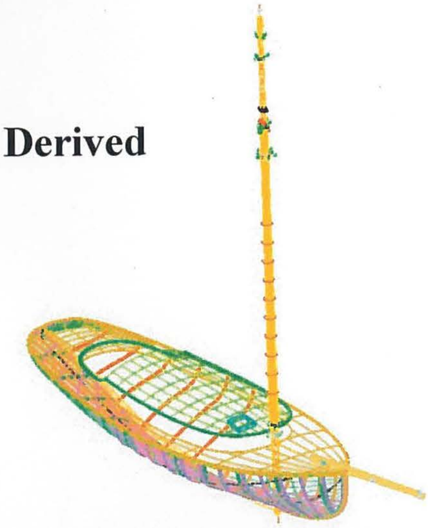
April 23 - May 31, 2014



Historic photographs contain dimensional data, because the objects in the photographs have dimensions. The question is: how can we extract them?

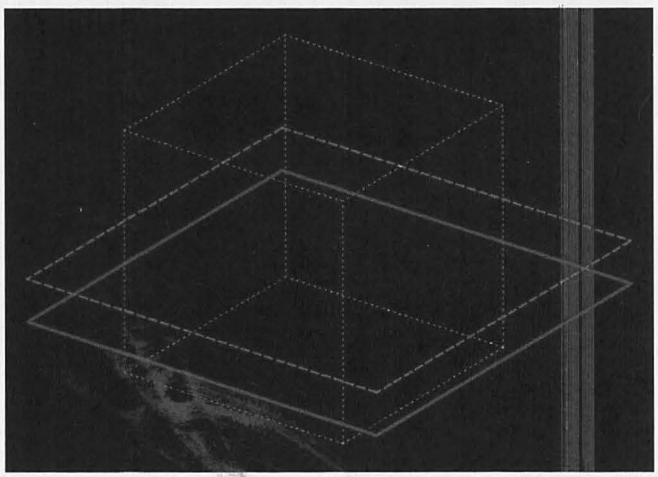
The method I use is not direct, because the historic photos for *Kathleen* were not taken with any intent to derive measurements. There are well-established photographically-based methods to derive dimensions directly from images using computer analysis or opto-mechanical systems. Their processes compensate for image perspective, parallax and lens distortions. Most of these systems rely on a series of photos taken in a specific, coordinated order in order to succeed. The historic photos by Walter Scott are my primary sources, but due to their varied orientations and unknown lens characteristics, they would not be useful in any of these systems. However, he took photos of *Kathleen* from numerous angles, which helps cancel out any distortions or errors that might result from depending solely on any one image.

My method could be called a sort of "digitally assisted reverse perspective analysis." It requires a computer and software, but only after the fact, since the photos were taken decades before electronic computers and software were invented. It relies on trial-and-error to narrow down dimensions, which makes it a more laborious process than established photogrammetric methods. It's "accuracy" also depends on the influences of a number of things, such as lens focal length and distortions, size and grain resolution of negatives, focus, camera shake, exposure and the tilt of the film plane to the lens axis. Some of these are unknown, but they can be "bracketed" or limited in some reasonable manner.

Briefly, using my method, I build up a virtual "restored" 3D ("three dimensional") model of *Kathleen* in commercial CAD software ("MicroStation" by Bentley Systems, Inc.), then I shoot "pictures" of it virtually ("visible line" projections from the CAD display). I use trial-and-error to find the model's orientations and the camera stations which best fit each of the historic photos shot by Walter Scott in 1910-11. I test each model "picture" for fit to the historic photos by using CAD software to lay the 2D ("two dimensional") projections from the 3D model over the historic photos for comparison. I make adjustments to the 3D model's orientation, camera location and perspectives until a very good match with each photo is found. I do all this under the argument that a CAD model must be accurate in its dimensions, shape and proportions if its projected images closely match all or most of the historic photos. It is a chicken-and-the-egg process, because the photos are needed to refine the model, but I must start with a model of some kind without the photos in order to have anything to compare to them. The only question left is one of scale, but that is already settled, because the "virtual" model is "full scale," based on the dimensions of the real *Kathleen* now resting in San Leandro, CA. There is no historical evidence that *Kathleen* was lengthened, widened, deepened or otherwise dramatically modified such that these basic dimensions changed appreciably at any time.

First Steps: Compare "As-is" *Kathleen* with historic photos

After working aboard *Kathleen* for several months, I wondered how severe any hogging aboard her might be, given her age. The diagonal plywood sheathing strips covered with fiberglas didn't show any notable distress as though the hull had hogged much after their application in the 1960s. There were no systematically broken frames or other signs on her interior that indicated great distress prior to fiberglassing. However, to check on any hogging, I decided to open separate 3D CAD files for three of the Walter Scott photos (Nos 362, 365 and 366), plus one recent image by Tim Campbell, taken in the 1990s. The reason for making four files is that the 3D "as-is" model of Kathleen (filename "Kathleen - 3D Rotated As Is Structure v19 for HLN projections and PC.dgn") has to be "attached" to each file. By "attaching" the model to a file (e.g. one named "Kathleen - 3D Space for Rotated Model v19 Historic Spar and Hull Study Photo No 366.dgn"), it displays "inside" the new file, where it can be rotated (roll, pitch, yaw) until its position produces a 2D projected image that matches the orientation of the Scott photo for which the file was created.[1] Attached files are called "reference" files, since they are used for reference only and their internal contents cannot be permanently altered when in a "referenced" state. It takes quite a bit of trial-and-error time to adjust a reference file's position inside another 3D file for these historic photos, and once the correct position is achieved, it should be saved and left unaltered. Trying to reuse the file that has been set up for Photo 366 for a different photo would result in so many different settings for the 3D model and the photo file itself that later attempts to recover settings for Photo 366 would be extremely difficult.[2]



Each "photo file" has these internal 3D elements: a dotted cube 65 feet on each edge, a green plane with dashed edges, and a bluegreen plane with solid edges.

I used the cube (shown here in an axonometric projection) to judge the amount of rotation and the degree of perspective applied to the 3D file (and its referenced model). There is no numerical way to quantify the focal length of the lens Scott used to make his photos, so I use trial-and-error in the CAD system to approximate Scott's shots. (It is not particularly important exactly where the referenced "as-is" model of *Kathleen* lies inside the cube, though it is best that the cube encompass all parts of the model.)

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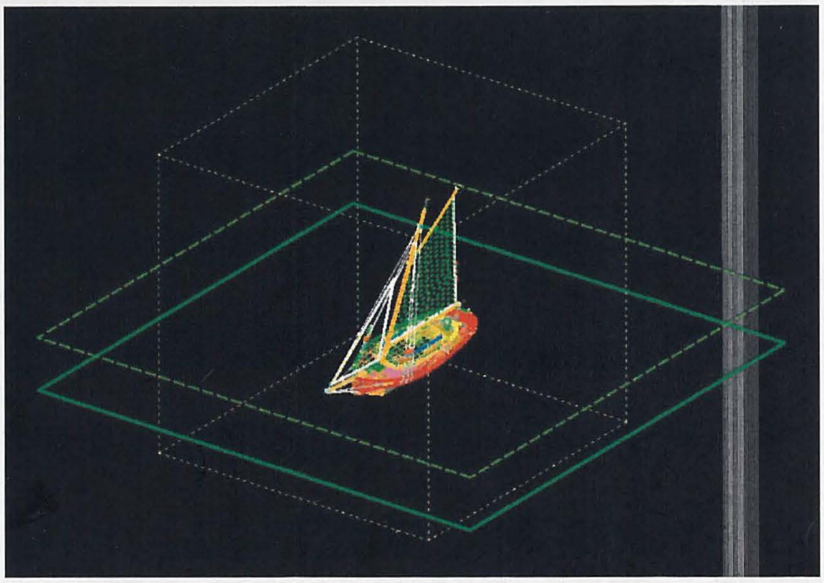
[1] It is much simpler to reorient an *entire file* as a reference file since it treats the entire model as a unit, instead of rotating selected individual elements from the model (such as hull and deck) apart from all others; the second method leaves all the undisplayed elements in the file **un**rotated and makes a gigantic mess.

[2] There is a tool within my CAD software which permits the user to "save views" as seen on the computer display. While this would save the orientation of the photo file in a recoverable way, it would not do so for the *attached* file in the sense that it could "automatically" rotate it to some other orientation for each saved view. "It doesn't work that way." However, it is possible to "attach" the same file for the "as-is" 3D model to a photo file several different times. The CAD software permits a user to turn each "instance" of a referenced file on or off, and each instance can be rotated independently of the others. Combining this capability with "saved views" might have permitted all the modeling work for all photos to be carried out in one file, however, in my judgement this would become confusing and very hard to follow for any future researcher, as well as for myself!

The dashed plane is intended to serve as the "horizon plane" for each photo; this plane is always level and may be lifted or lowered with respect to the referenced model file. When a camera shoots any average terrestrial photo (where the lens axis is parallel to the earth's surface), there is always a "horizon" in the photo — this concept is illustrated most easily by shots taken at sea — the distant level surface of the ocean is the photo's horizon. The camera is always located within this horizon plane, so when the CAD system "shoots" a 2D "photo" of a 3D model of *Kathleen*, this green "horizon plane" *should show as a line* to indicate that the CAD system's "camera" is in the plane proper.

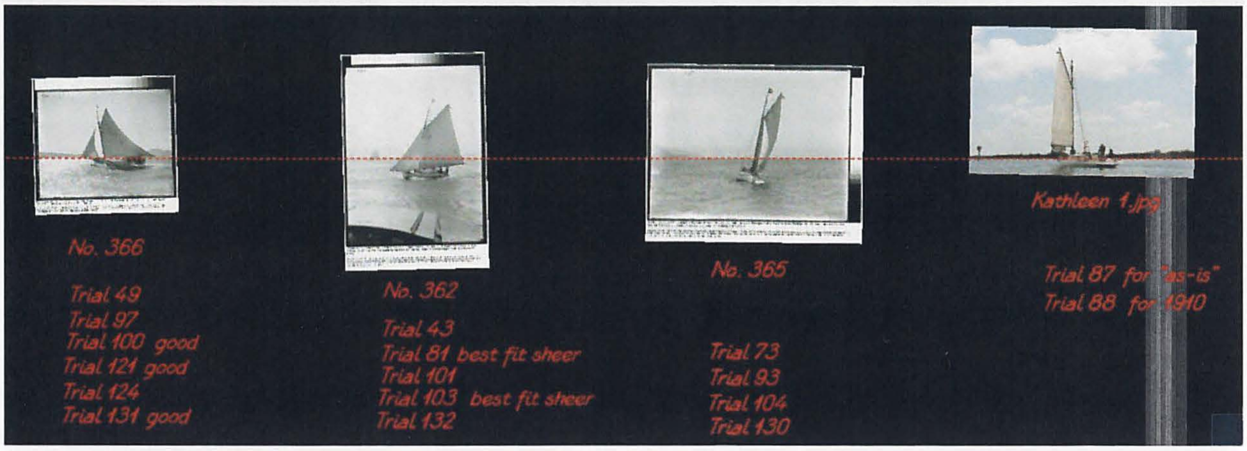
The solid green plane is intended to serve as the surface of the water. Obviously it doesn't reproduce waves and choppy seas, but it can help judging the roll and pitch of the referenced *Kathleen* model when trying to recreate Scott's shots precisely. This plane is always level, and it too may be lifted or lowered with respect to the referenced model. However, in a 2D projection, it should always lie "below" the model, just as the water's surface was always below Scott's camera.



The 3D "as-is" model of *Kathleen* referenced to a typical 3D "photo file" with its typical 3D elements, shown as an axonometric projection..

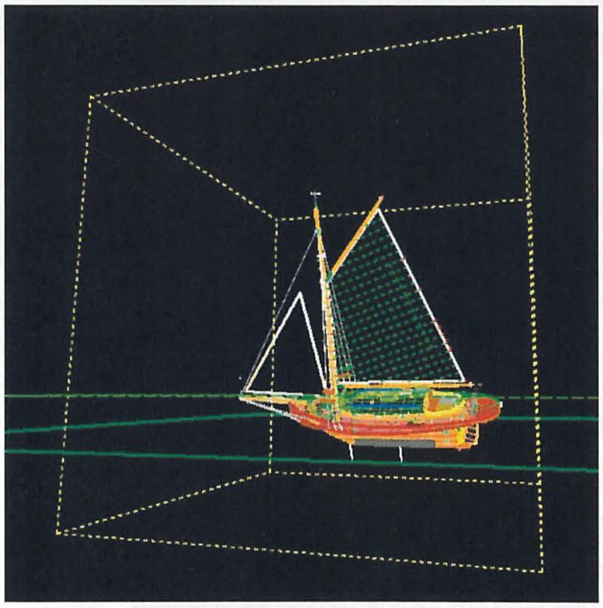
To "recreate" a particular Walter Scott photo — say No. 366 — from its associated 3D CAD file, the referenced model of "as-is" *Kathleen* must be adjusted for roll and pitch with respect to the water's surface, the horizon must be adjusted up or down with respect to "sea level," the 3D photo file must be rotated vertically until the horizon plane becomes a line, and finally the perspective (analogous to lens focal length) must be adjusted. (Usually adjusting the perspective upsets the horizon and vice versa, so this is an iterative process also.) A tool in the CAD system called "Export Visible Lines" must be set up to produce a *2D file* that captures how the image of the model setup "looks" on-screen. The resulting 2D file is a CAD vector file with an ".hln" extension (for **h**idden **l**i**n**e file). This file type is not a raster image, like a "screen shot" or digital photograph. (An .hln file has the same internal vector file format structure as MicroStation's .dgn files for 2D and 3D CAD files.) It can take 20 or 30 separate .hln files to zero in on the exact camera station and perspective which reproduces any one photo. There is no "automatic" way to do this, and I haven't found any shortcuts to speed up the process.

I set up a third kind of CAD file, a 2D file in which the four historic photographs mentioned above are referenced side-by-side as raster images. The filename is "Kathleen - 2D Historic Spar and Hull Study Photo & HLN overlays v1.dgn" The photos are not attached at any particular "scale" because none applies in any uniform fashion, though the images are displayed at approximately the same size. I drew a horizontal red dotted line to serve as a guide for rotating all the photos till their horizons matched this "level" line. This made each image "level" and in a better position for comparing the 2D files exported from the 3D photo files. The images are very high resolution scans of 6½" x 8½" glass plate negatives, to make as much detail as possible visible on screen for comparison to the 2D files exported from the 3D model.

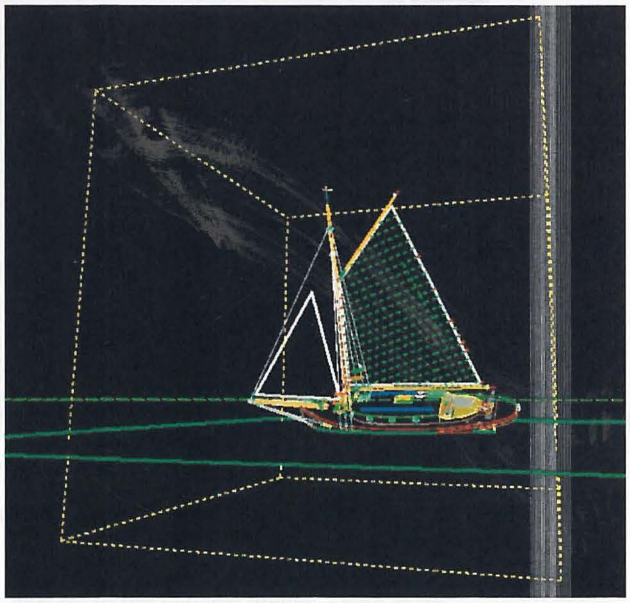


Screenshot showing the layout of the first four photos I used for this project. (Others were added later.) I labeled each photo with its primary negative number, and beneath it I recorded the numbers of the more successful trials. After a while I stopped keeping verbal track of the trials in this CAD file, because I re-used the exported file names 15 or 20 times as a means to save time over repositioning and rescaling every new exported file. Reusing an existing referenced file name for an established camera station simply allows new or changed data to "slip into place" automatically. Often I made screenshots of various stages in the reuse of a file, if results were important to record.

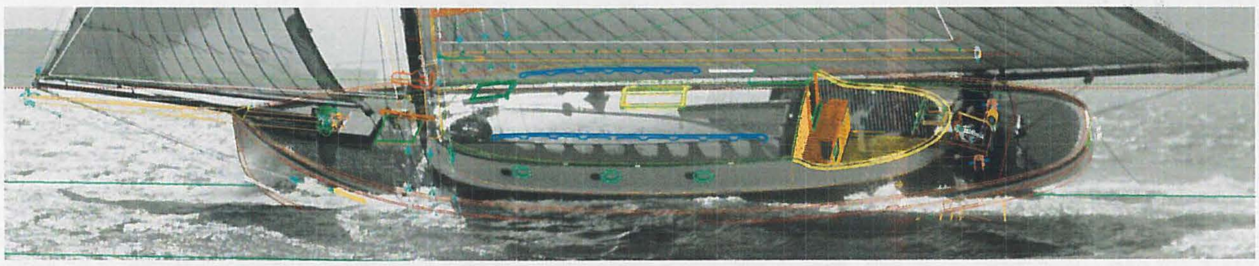
The process of "exporting" or generating a 2D "hidden line file" creates a file where the "wireframe" or transparent display of the 3D "as-is" solid model is processed to remove all the "hidden" lines which would not show if the model were treated as an opaque solid.



3D wireframe display of "as-is" model of *Kathleen* after several trial exported 2D views have resulted in a very close comparison to Walter Scott's Photo No. 366.

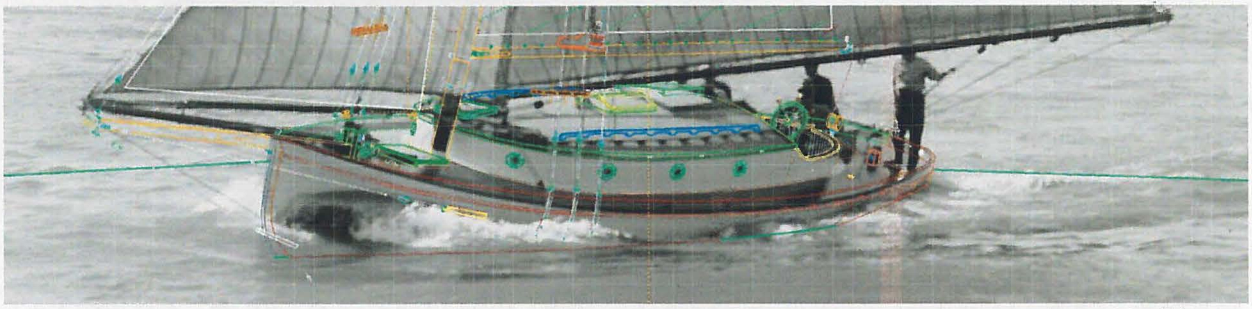


2D "hidden lines" projection of the 3D file at left showing only visible lines from the model solids. The hidden lines don't appear when a model is rendered as a solid.

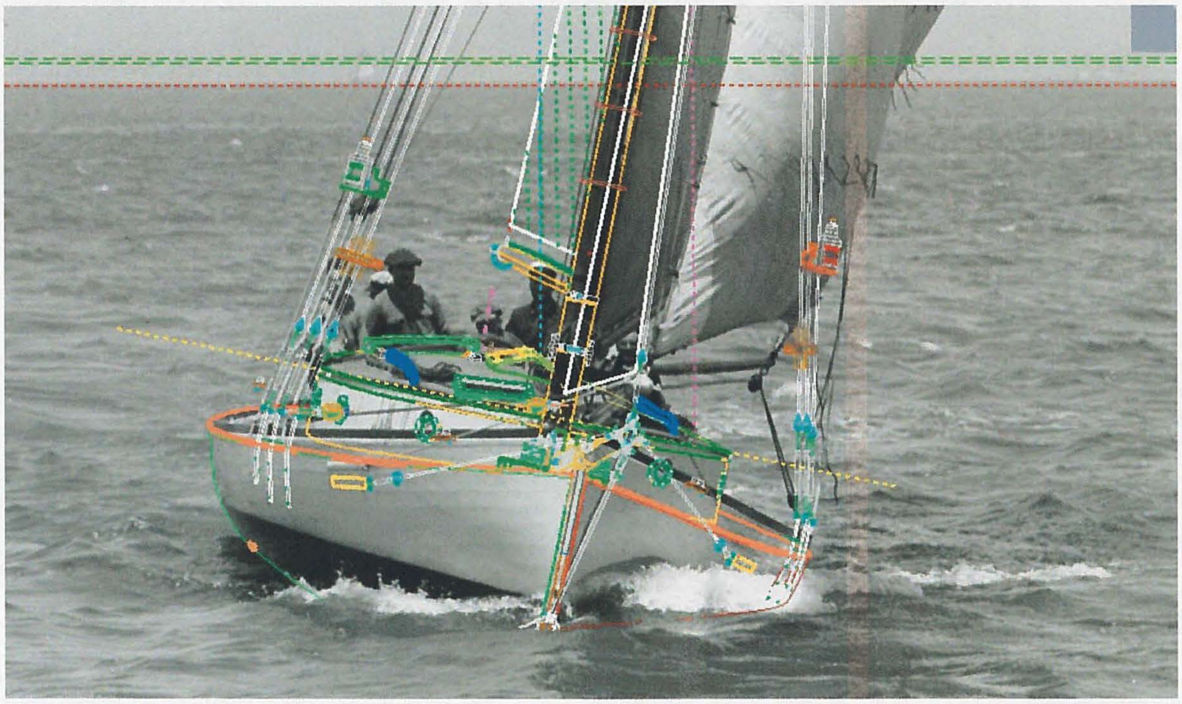


Detail of above view with "as-is" model superimposed on the 1910 photograph. Note that the sheer amidships is much deeper in 1910 than in the 2012 "as-is" model.

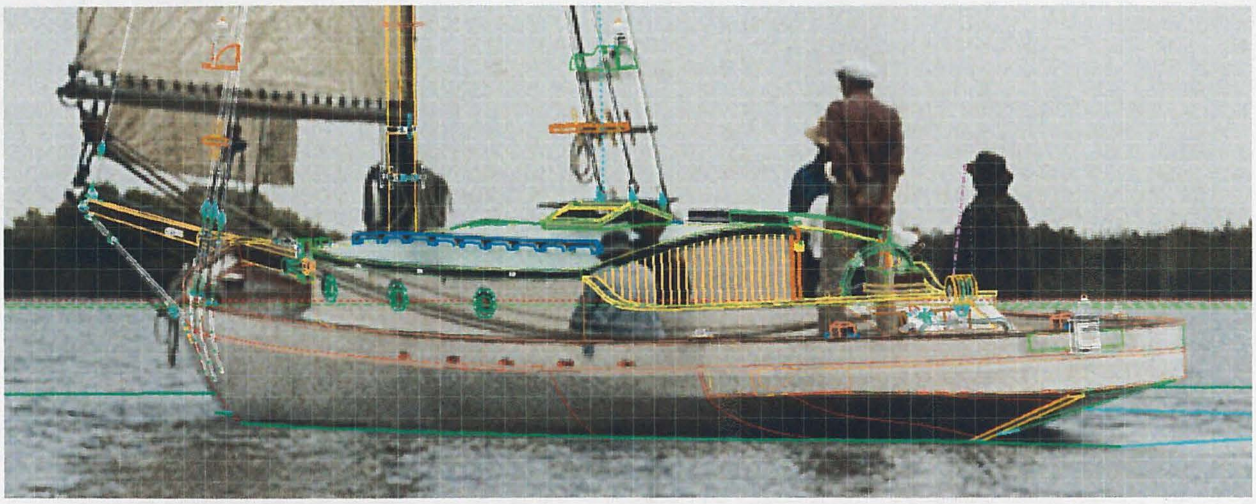
I set up similar files and procedures for Photos 362 and 365 and Campbell's photo. The results follow:



A 2D visible lines projection from the 2012 "as-is" 3D model of *Kathleen* superimposed on Scott Photo No. 362, with the cabin and midships area of the deck sheer aligned. Note that bow and stern of the projection fall well below corresponding features in the photo. This is a clear indication that the 2012 hull has hogged.



A 2D visible lines projection from the 2012 "as-is" model of *Kathleen* superimposed on Scott Photo No. 365. It is very clear from this image that though the projection of the cabin and midships of the 3D model coincide with the photo, the bow is a good 10" below the bow features in the photo. A great deal of hog has occurred.



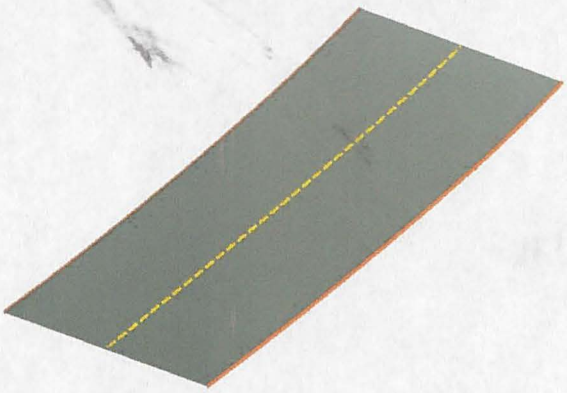
2D visible lines projection of the 2012 model of *Kathleen* superimposed on Campbell's photo. It's clear the 3D model based on measurements made in 2012 accurately reproduces the vessel's conditions in the 1990s.

Next steps: determine initial information for a "restored" 3D model of *Kathleen*:

Now that I was able to prove that *Kathleen* had certainly hogged since 1910, what was the next reasonable course of action to produce a restored hull with no hog? The photo/as-is-model comparisons were able to give me a good idea how much hog there was, but it was now a matter how to work with this in 3D CAD modeling. What information was it reasonable to assume had ***not*** changed since 1910 (or even 1904), so I had a starting place for a "restored" model?

While the sheer had flattened in profile, there is no indication the deck changed shape *in plan*. Thus, I could use the CAD software to create a vertical surface or "wrap-around" envelope that outlined the deck shape *in plan* for any kind of sheer I might need to try out. A sheer *line* for the hull could be created by finding the intersection between a horizontal surface contoured to the sheer line *profile* through the vertical wrap-around surface. This intersection line is very easy to find using CAD software tools. I thought a trial-and-error approach would work best, beginning with "Trial 1" as an estimated sheer.

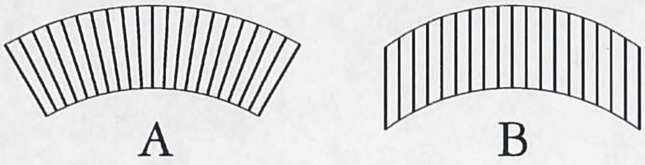
Vertical "wrap-around" surface projected from a trace of the edge of *Kathleen*'s deck in a horizontal plane.



Horizontal projection of a sheer line for *Kathleen*'s deck as seen in profile. Trial #1 was a "guesstimated" starting point which I expected to modify many times.

There is no attempt to compensate for deck camber in this initial approach, because the camber could be "anything" between the same port and starboard sheer lines. Camber is an issue to settle, but is not essential to these first steps. I also made sure the port and starboard sides of the vertical "wrap-around" surface were symmetrical for the purposes of the "restoration" 3D model, in the belief that most shipbuilders intend their products to be symmetrical, even if they don't turn out exactly that way during construction.

After repeated trials produced an accurate historic sheer, my plan was to "hang" sections of the 2012 hull off the new sheer, at appropriate stations along the hull length, believing that when a hull hogs its sections behave more like Case B than Case A in the diagram below. I could then generate "restored" hull surfaces through the newly placed sections.



Because deck and hull planking don't stretch much when a hull is "bent," condition B shows what most likely happens to hull sections as a hull hogs: they generally "slide" parallel to each other and retain most of their original shape.

In my trials to discover the best 3D deck sheer I eventually began to work out the sheer of the deck *centerline*, basing it on the camber of deck beams at the front and back of *Kathleen's* cabin. I double-checked the accuracy of my estimates by finding the intersection of the cambered deck in the 3D model with the outer surface of the cabin, since this junction shows up in the Walter Scott photographs. As my "experiments" or series of trails progressed, Trial #5 for the deck began to look like a very good match to the historic photos:

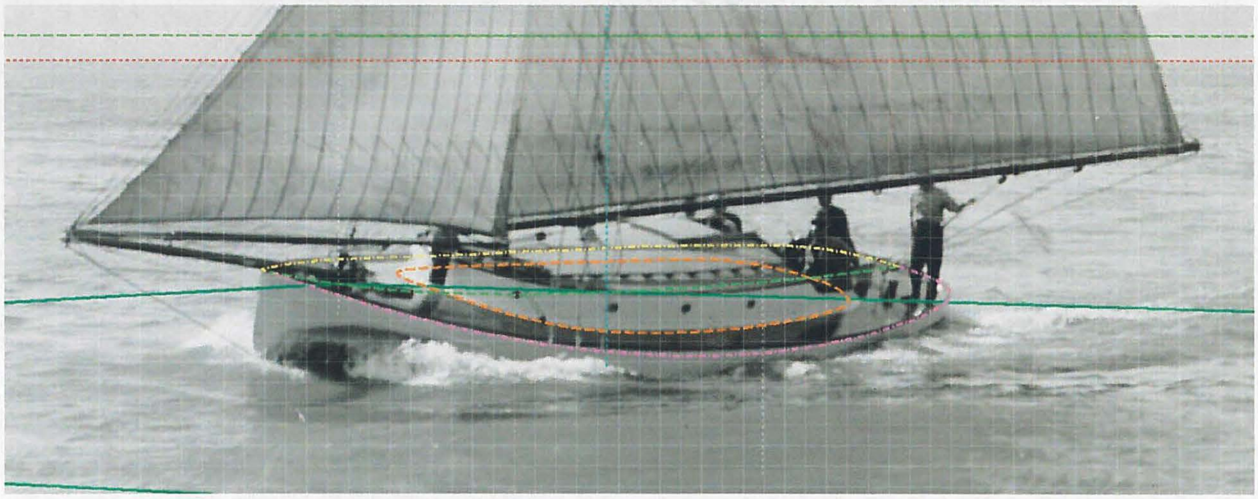


Photo 362 with projection from 3D model of Deck Trial #5 superimposed. The 3D model's sheer line port and starboard looks in very close alignment with the photograph.

However, closer inspection revealed that the model's sheer line and Photo 365 did not match very well astern, despite the better appearances in Photos 362 and 366.

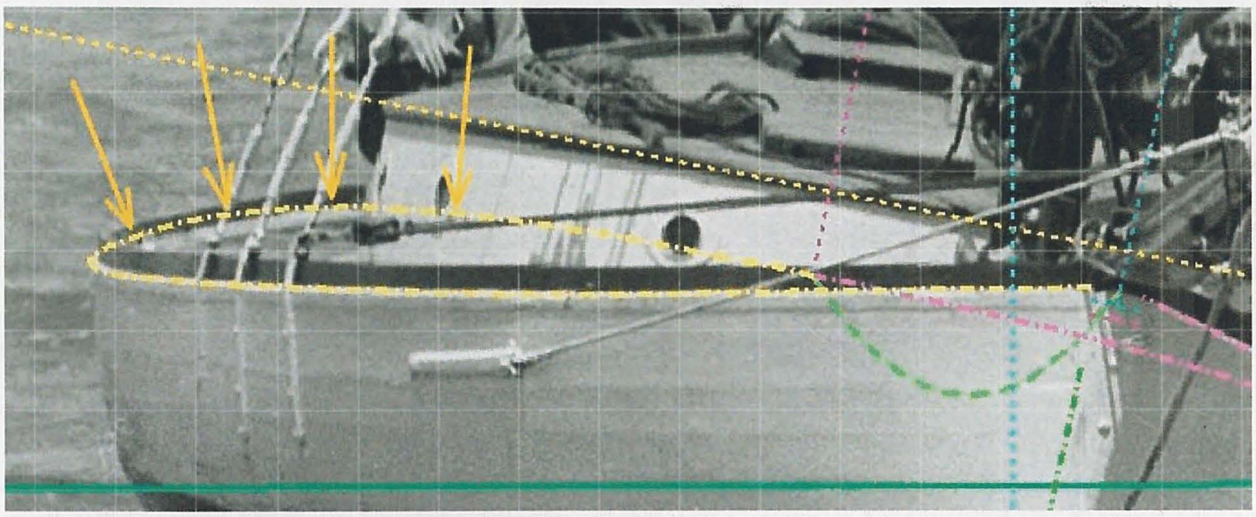
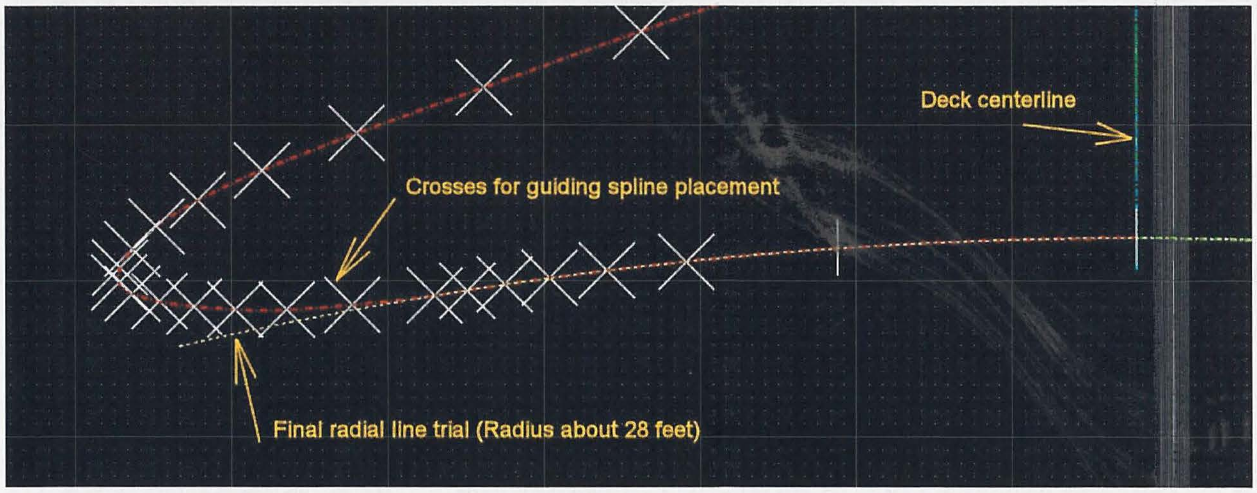
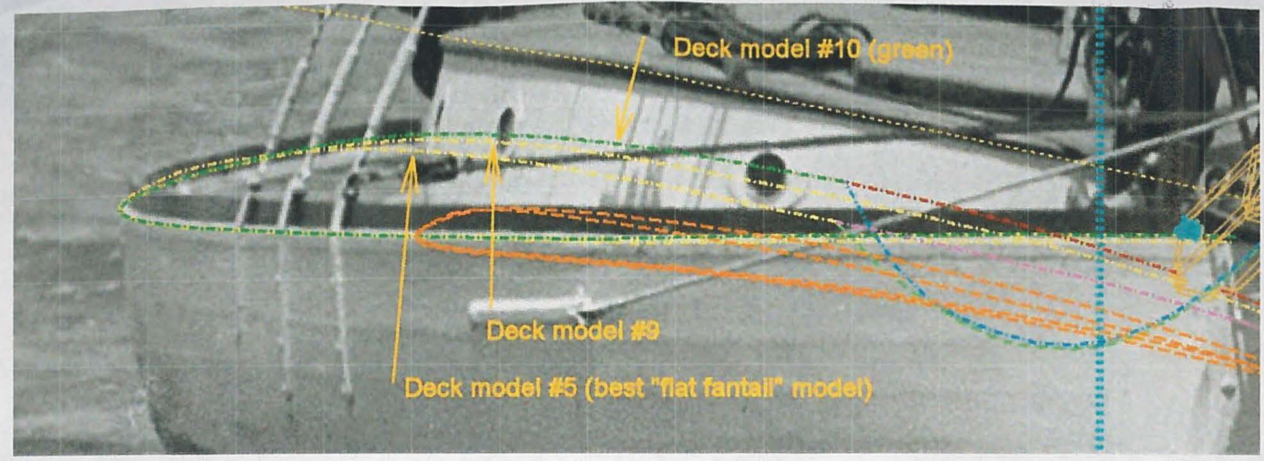


Photo 365 with projection from 3D model of Deck Trial #5 superimposed. Here it is apparent that something is amiss in the stern: the yellow sheer line from the model doesn't match the photo where the arrows point. The "drooping" dotted green line to the right side of this image is the deck centerline projected onto the image.

Variations on the deck profile did not improve this result, so I began to experiment with the idea that the fantail of *Kathleen* was cambered as seen *from astern*, not simply from port to starboard through the deck centerline as I had been assuming. The latter approach results in a fantail that is flatter the further aft one goes. A cambered fantail might correct the mismatch.


Deck centerline
Crosses for guiding spline placement
Final radial line trial (Radius about 28 feet)

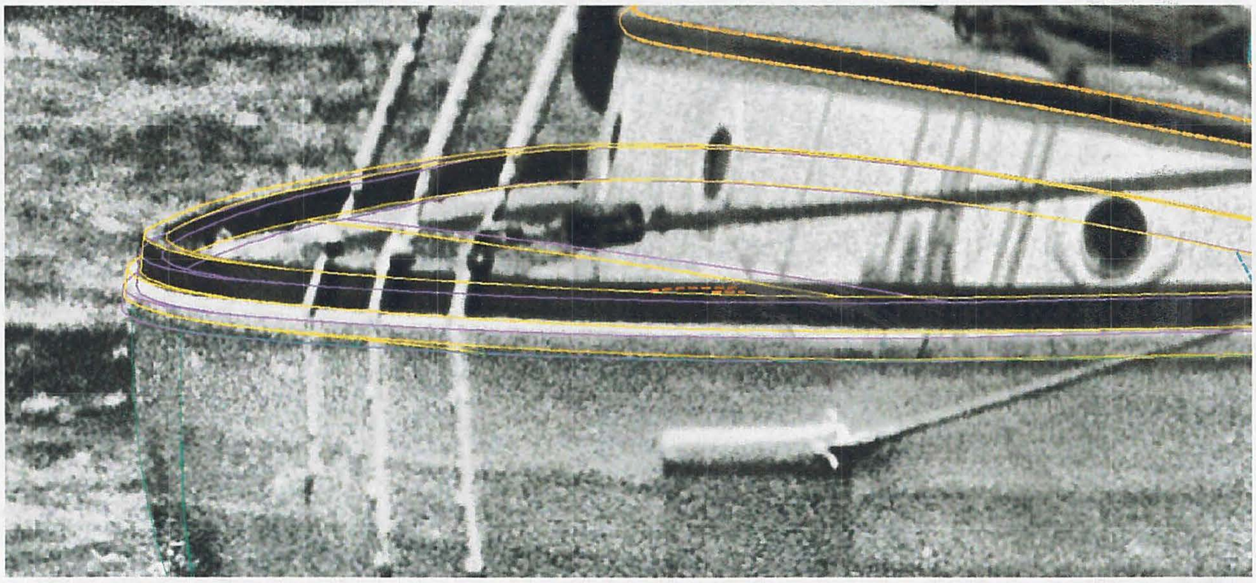
Seen from astern, Deck Trial #10 has a camber of about 28-foot radius at the extreme stern, and this appears to cure the mismatch between the 3D model and Photo 365.



The stern sheer of Deck Trial #10 has a much better fit to the toe rail than any other curve back aft, so I concluded I had approximated the deck shape and sheer well enough to call this series of trials "finished."

However, as I began to create a solid for the deck and add the historic toe rail into the 3D model, 2D projections of the deck with the toe rail quickly revealed the fact that I had more work to do on the historic sheer. Principally I needed to *raise* the sheer midships about an inch. (This meant a reworking of the hull surfaces below as well, since I had proceeded to develop them on the assumption that I had correctly captured the historic sheer. I would rather address production of the hull shape as a separate issue from the historic sheer.)

The following image shows Deck Trial #10 with its toe rail in purple lines, while Deck Trial #12 with its toe rail is shown with yellow lines. The cabin roof model is unchanged.



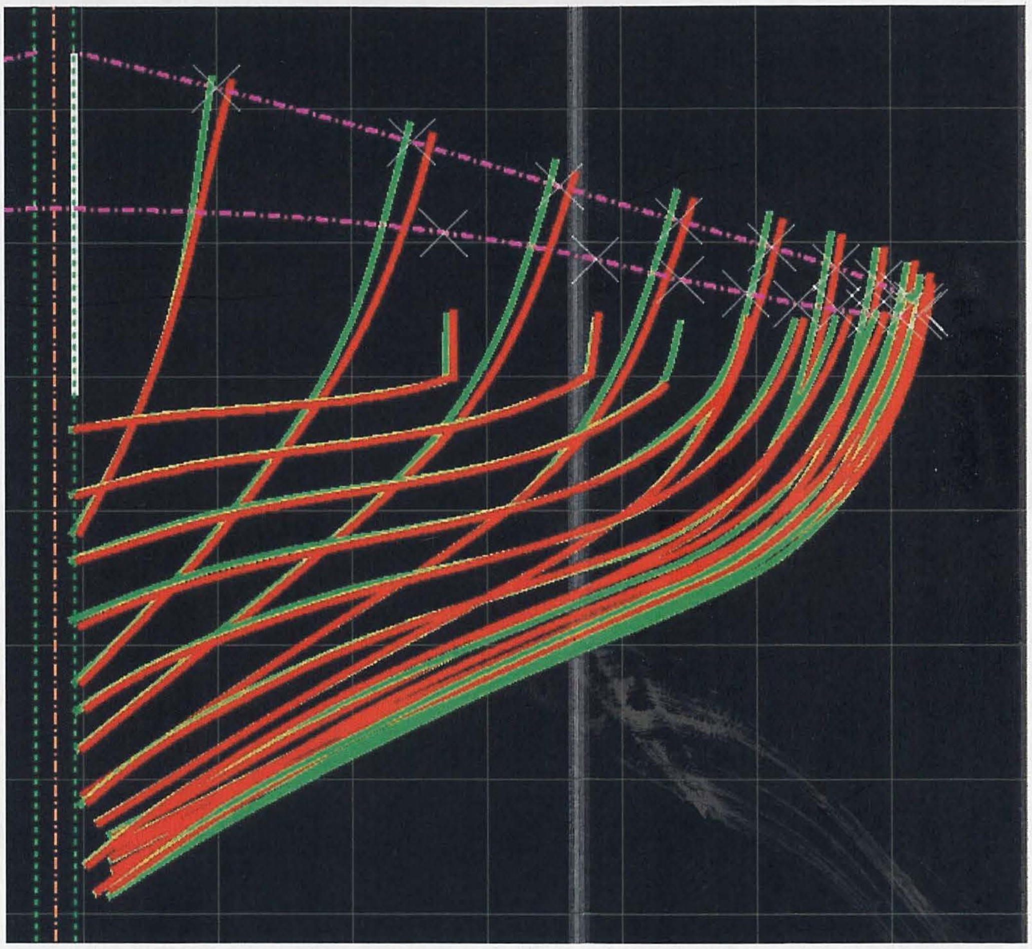
Kathleen Photo 365 with Deck Trial #10 and toe rail (purple) superimposed on Deck Trial #12 and toe rail (yellow).

It also was apparent that a deck 1½" thick fitted this photo better than a 1" thick deck.

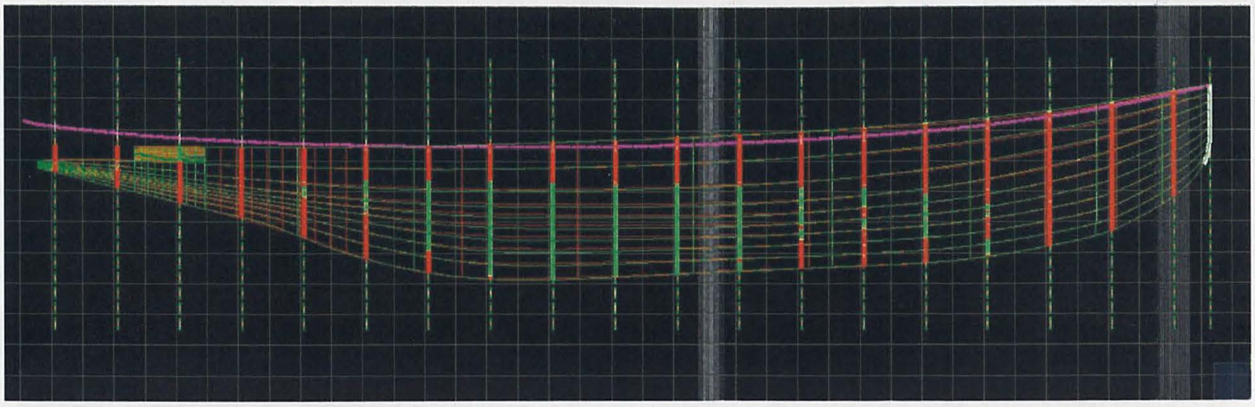
From here, I proceeded to work out the new "restored" hull shape in the 3D model. (The hull needed to be redone after the 1" change in sheer amidships. CAD makes no automatic change in the hull just because the deck shape is altered.)

As I worked out the deck shape, I also worked out historic spar lengths and their scantlings, followed by the shape of the cabin roof. The actual shape of the hull was derived independently from these things.

Earlier, while working on the "as-is" conditions of *Kathleen*'s hull, I had used the 3D CAD program to "mirror" body sections from the port side of the hull to the starboard side. ("Mirroring" means to copy in reverse to the other side of a centerline.) The sections were cut on a 2-foot spacing from the plank surface of the 2012 hull model, working fore and aft from a section taken at the point of maximum beam. It was immediately apparent that the existing hull was not symmetrical; in some places the differences were well over an inch. The screenshot below not only compares the port and starboard sections of the 2012 hull about the vessel centerline plane, it compares them with the "restored" sheer as well:

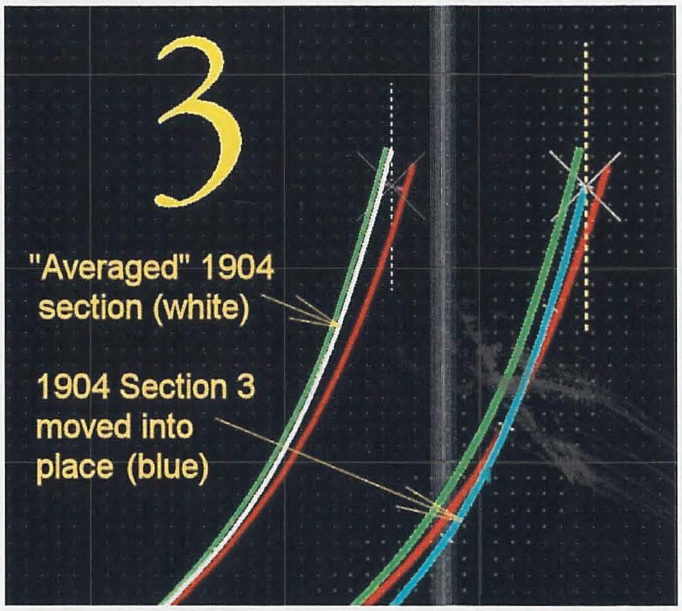


Port (red) and starboard (green) sections of 2012 hull overlaid on 1904 sheer (purple), which is at the underside of the deck. The "X" marks show the intersections of the section planes with the 1904 "hull" sheer, to indicate where the tops of hull sections should terminate at the underside of the deck in a "restored" hull. Scott's photos show that the deck (or covering board) lies proud of the hull by at about ½" to $^3/_4$", so sections must terminate under the deck. The vertical green dotted lines at left indicate the stem rabbet which is offset $1^3/_4$" from the vessel centerline.



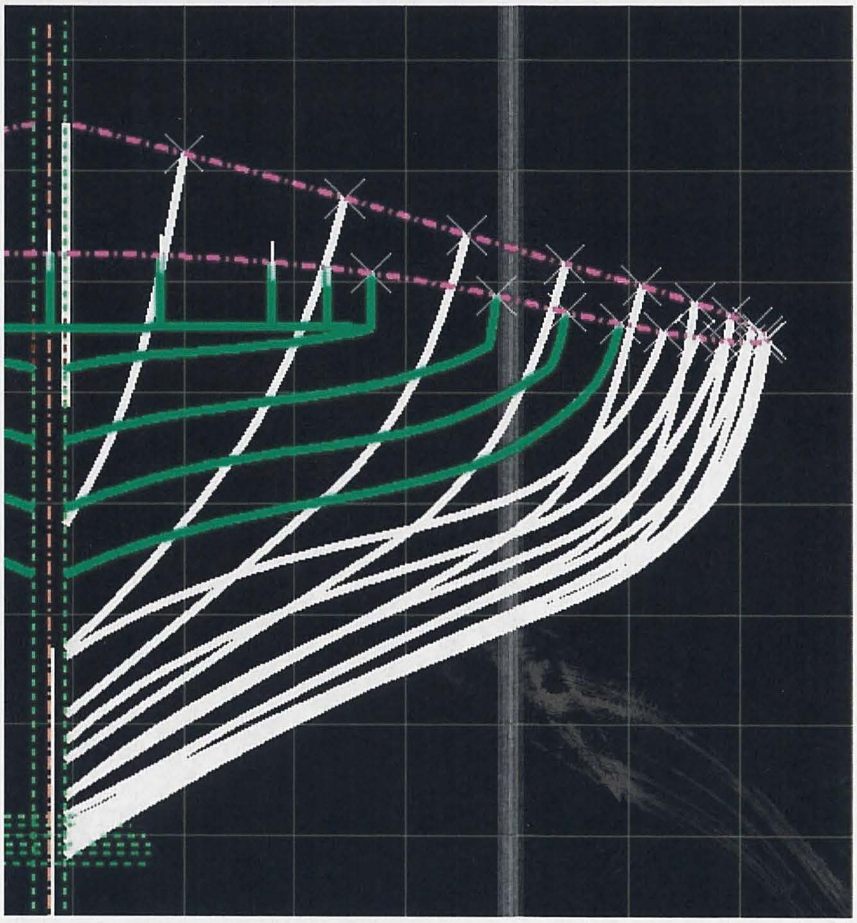
Profile of 2012 hull surfaces with 1904 sheer laid in (purple line), along with sections cut from port and starboard sides of 2012 hull. Vertical dashed lines are stations for section planes.

If a sheer line were drawn through the tops of the 2012 sections in the body plan above, it would obviously not coincide with the 1904 sheer, and it would fall further below the 1904 sheer at the stern than at the bow (see the profile view above also). With this data, the question is "what did Orlando Pasquinucci intend the 1904 hull to look like?" Obviously I cannot consult the builder directly, and no builder's models of *Kathleen* are known to survive. There are only Walter Scott's photos to use to check any modeling work. Therefore, I am left to guess at the historic shape, but I will be doing that within certain defined limits. The "envelope" of uncertainty is perhaps +/- ½" or at most +/- $^3/_4$".

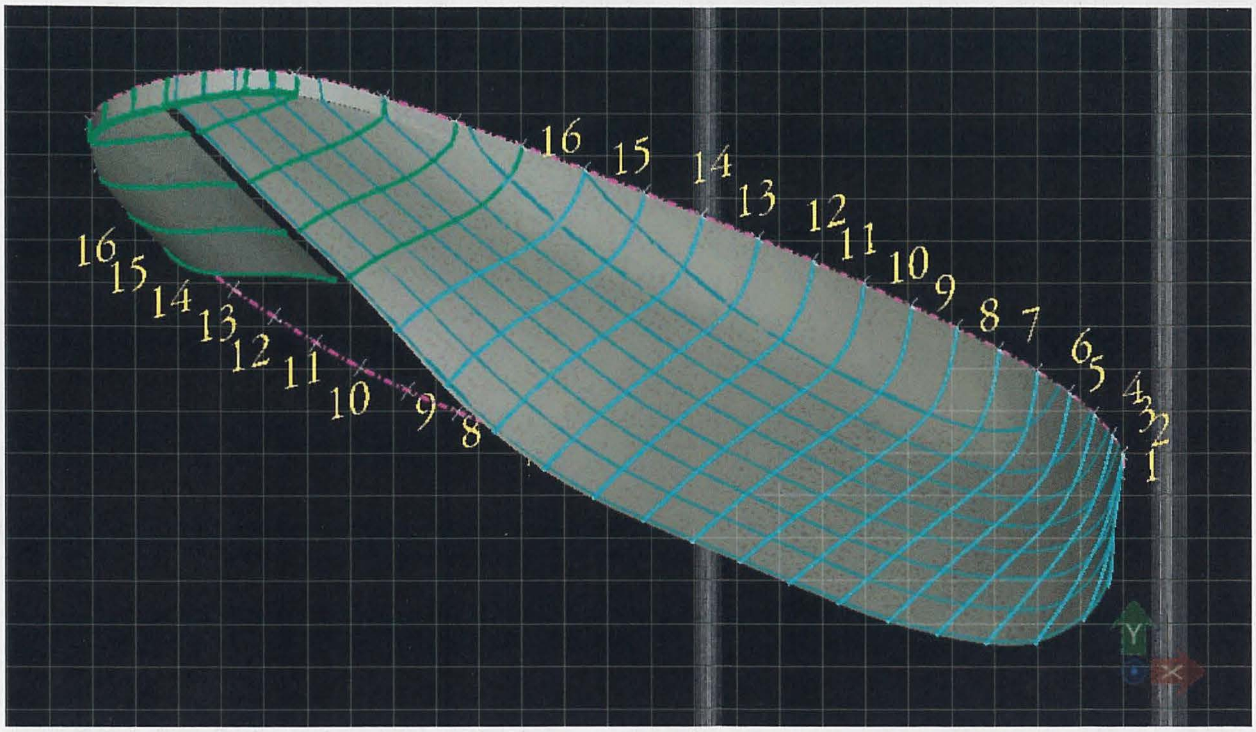

3
"Averaged" 1904 section (white)
1904 Section 3 moved into place (blue)

Development of 1904 Section for Station 3, as typical example for sections of *Kathleen.*

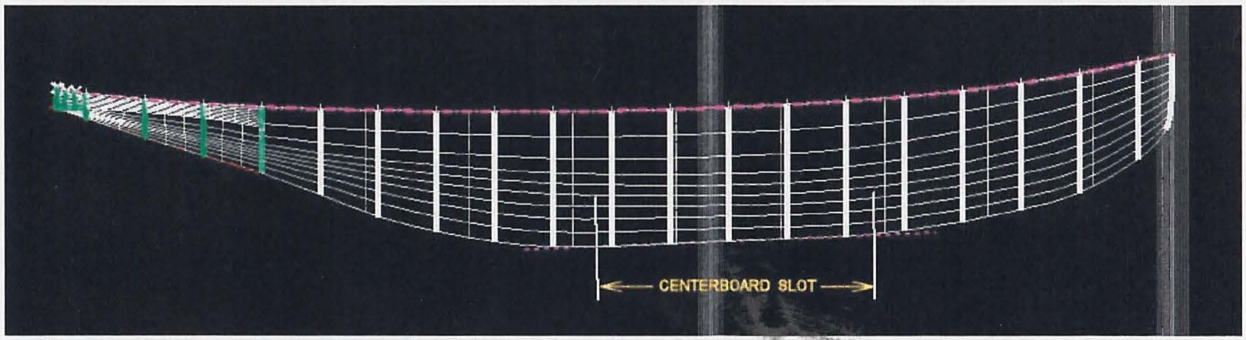
I decided to follow several steps to develop "restored" sections. First, draw vertical lines through the "X" marks on the 1904 hull sheer. Second, draw new a section in each of the section planes, averaging a course between the 2012 port and starboard sections, and terminating at the vertical line passing through the "X" mark. Third, when a new section is moved into place (in effect, backing out the hog), it should move only in a vertical direction, never horizontal. Fourth, the top end of each new section should touch the hull sheer at the "X" mark corresponding to its section plane. This approach does not guarantee a fair hull surface at the start, but it provides initial conditions that can be refined, faired and compared to Walter Scott's photographs. The CAD software can fair a "B-spline surface" over successive curved sections, even if kinks or bumps show up. There are several ways to check this surface for true fairness. First, I can cut buttocks and waterlines from the new hull surface by finding the intersection lines between the surface and buttock or waterline planes. The new "lines" can reveal fair and unfair conditions. Second, I can "roll" the 3D model around to look at it from various angles to see if each section line is fair all by itself. Alternatively, the software can "render" the surface (treat it as a lighted solid), so I use the reflection of the "default lighting" in the software window to check for discontinuities and ripples in the surface.



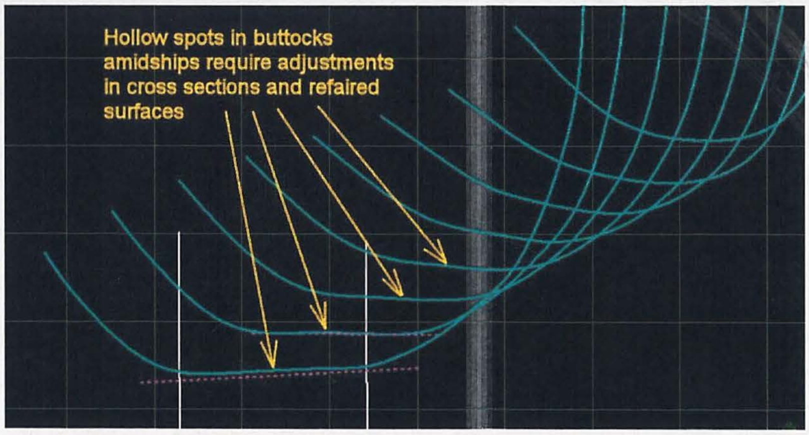
Redrawn sections with tops at new "hull sheer line." The vertical lines through the "X" marks have been turned off for this view. The heavy green lines are sections of the counter, whose surface in CAD is discontinuous with the rest of the hull due to the sternpost and sternband..



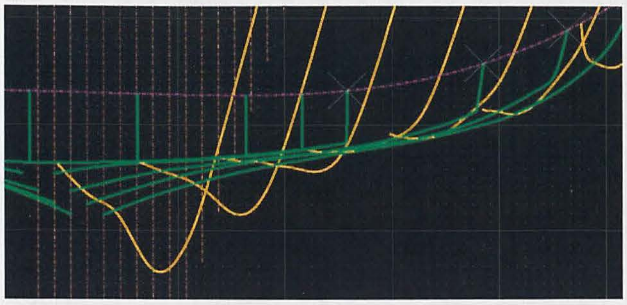
First trial surfaces of "restored" hull. From a distance, things look very good! The numerals are for the section planes (2-foot spacing). Buttocks were cut at 9-inch spacing.



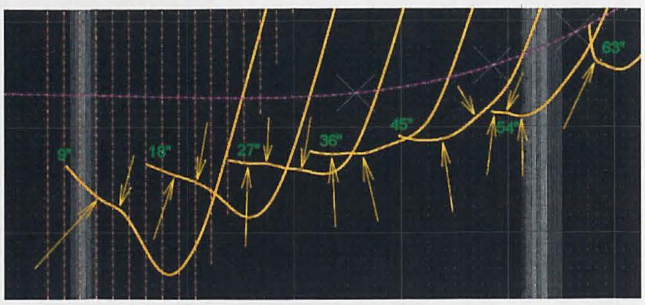
Profile view of first trials for "restored" hull with indications for centerboard slot position. Rabbet in this area must be a tangent, as it is in the hull in 2012.



Hollow spots in buttocks amidships require adjustments in cross sections and refaired surfaces



"Wiggles" in buttocks of counter, cut from surface.

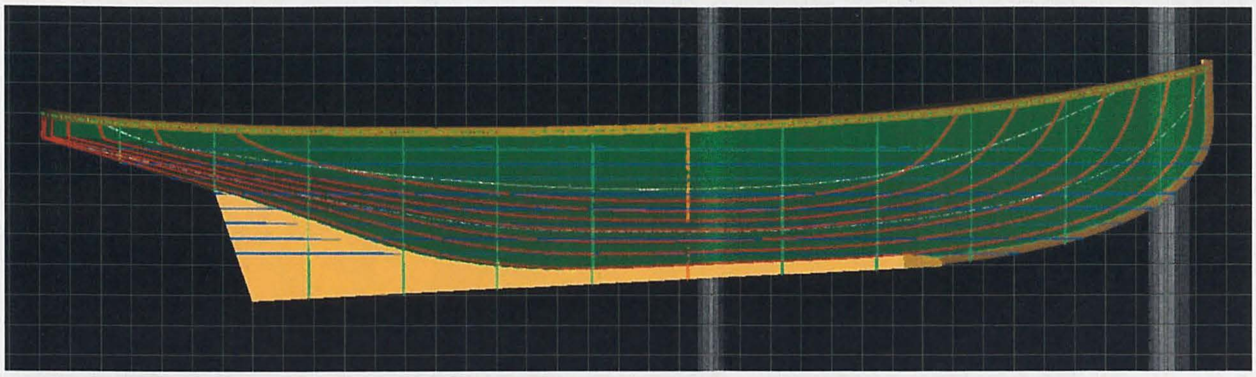


"Wiggles" pointed out in buttocks, with sections turned off.

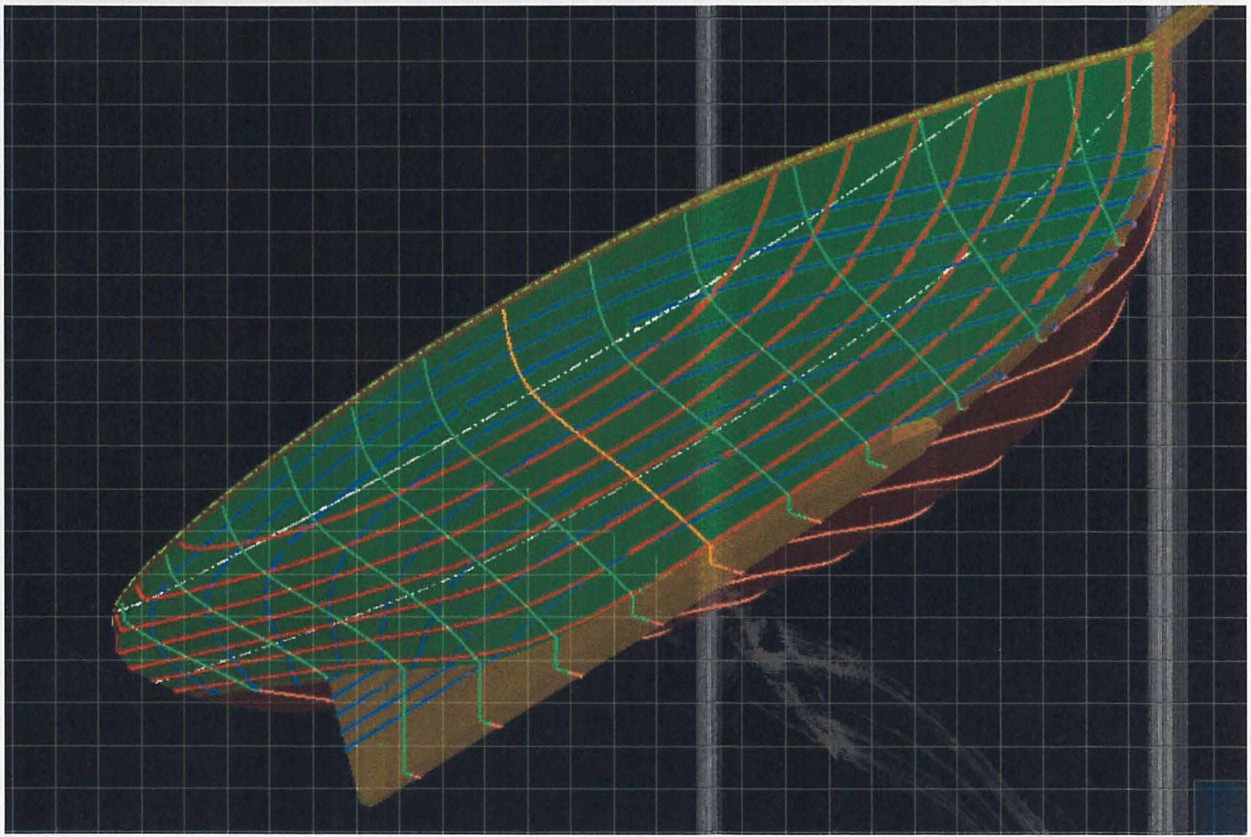
The bumps and wiggles in buttocks have to be addressed by changing the sections, usually by redrawing them one by one several times, followed by regenerating surfaces through revised sections until results are "fair enough," as judged by cutting buttocks and waterlines for "checks" on the fairness of newer surfaces. Every so often a "reality check" is needed, because the "wiggles" visible in the CAD display when "zoomed in" can amount to tiny fractions of an inch that would never be considered significant by a wooden shipbuilder. Just for appearances' sake I only addressed variances that were greater than $^1/_{16}$". Those lesser ones I left alone, lest I be chasing finer and finer "wiggles" to no practical purpose.

There is a further check on the fairness of a CAD-generated hull surface, and that is whether it can be "thickened" into a solid representing hull planking. (*Kathleen*'s planking is 1" Port Orford cedar.) If a surface will not "thicken," then there is a problem somewhere in the surface or on its edges. (A persistent problem has occurred where the hull surface fairs into the spline representing the stem rabbet: there is a quirk that occurs at the bottom of the spline which is hard to get rid of and still maintain the curve of the rabbet in the forefoot, but unless it is minimized or eliminated, the rest of the surface will not "thicken!") There is no analogy to this process in traditional hand-drawn drawings or lofting; the best analog is probably bending planks to frames, something that is too expensive to do for development trials. Beyond addressing quirks and blips in the edges of a surface, my CAD software contains tools which mathematically "rebuild" B-spline curves and surfaces in such a way as to smooth out unusual bumps, but such tools must be used carefully, or they introduce as many errors as they cure, hence the resort to hand-adjusted sections. After some experimentation, I found that setting the surface-rebuilding tool to "15 nodes" for both "axes" of a problem surface would generally make it "thickenable" without introducing gross errors in the surface compared to its generating sections.

Beyond this point, the next "test" for fair surfaces that can be "thickened," is whether the resulting CAD solids can be "cut" into individual planks or "shaped" to fit rabbets or the knuckle at the sternband. They also must be able to "union" into a continuous solid from stem to stern in order to cut full-length planks. This last capability also introduced some frustrating steps. Just because two B-spline surfaces meet at a common B-spline curve does not mean their thickened solids will unite to form a single solid. The "rules" governing what will or won't "work" in these situations aren't clear from the CAD software's "help" files or on-line inquiries to various forums. I had to develop successful work-arounds by trial-and-error. Eventually, the following 3D model of a faired 1904 hull was derived, where the CAD solids were able to be manipulated for further work as a construction model was built upon the "restored" lines I developed.

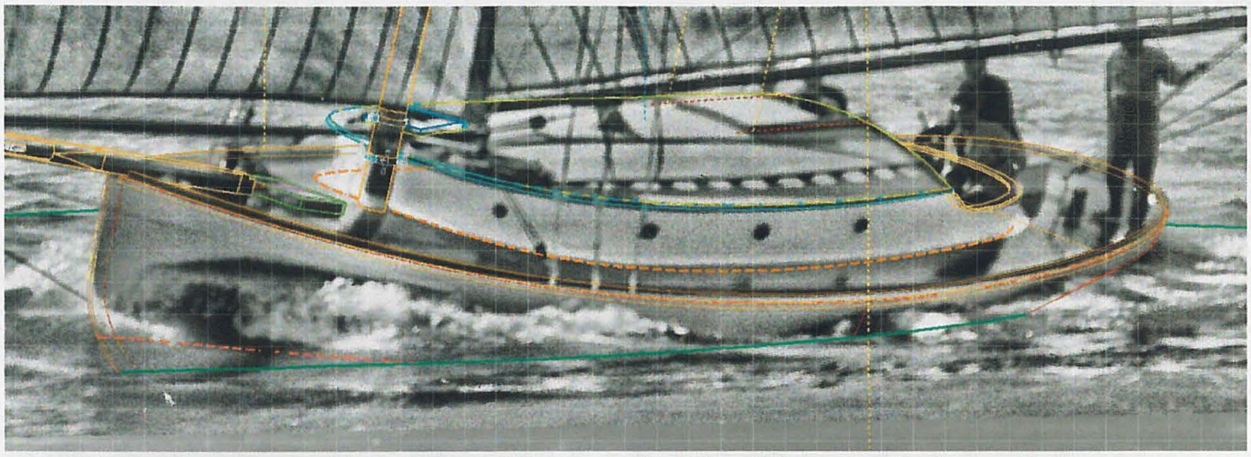


Profile of Draft 14 for 1904 "restored" hull of *Kathleen*, with lines superimposed on planking surface. The rake of the sternpost is arbitrary at this point, but the keel is widened at the centerboard slot.

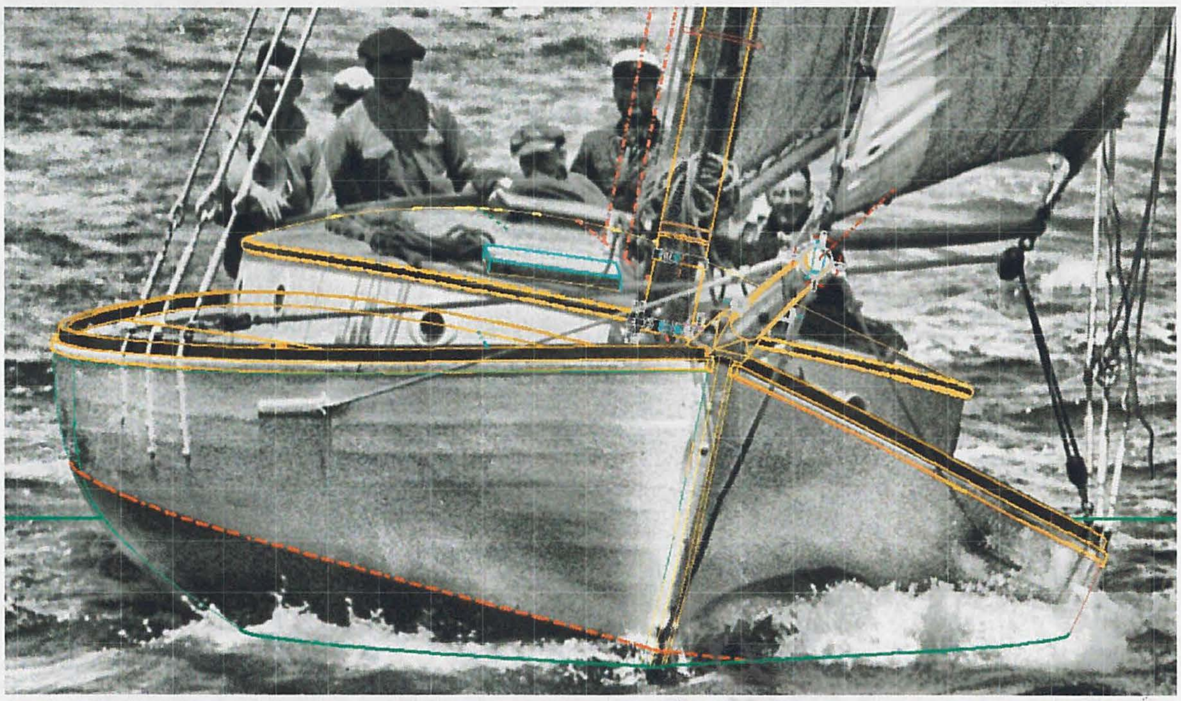


Axonometric view of Draft 14 for 1904 "restored" hull of *Kathleen*, lines superimposed on planking surface.

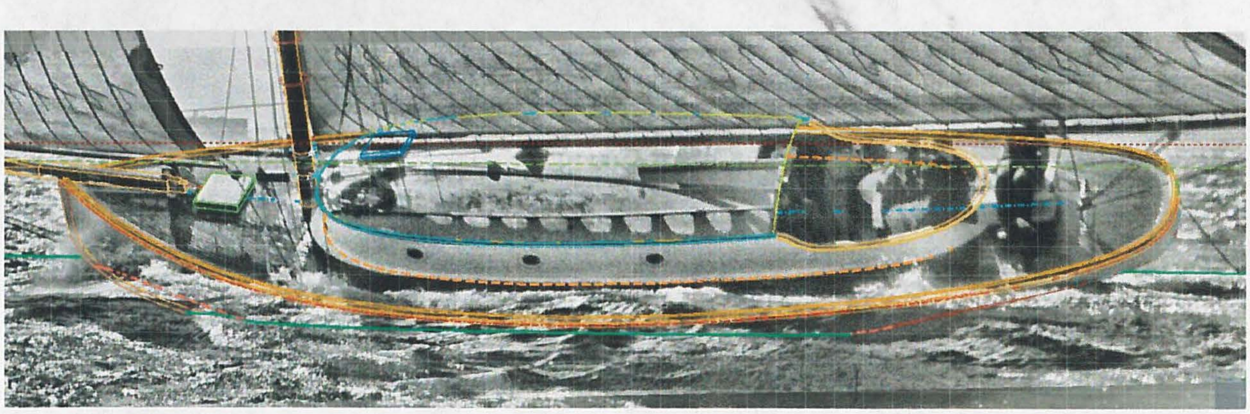
The following pages contain images showing how this model fits Photos 362, 365 and 366. Those projections are the final "test" for the accuracy of the "restored" lines and hull.



Draft 14 hull with spars and cabin roof exported for camera location of Walter Scott's photo no. 362.



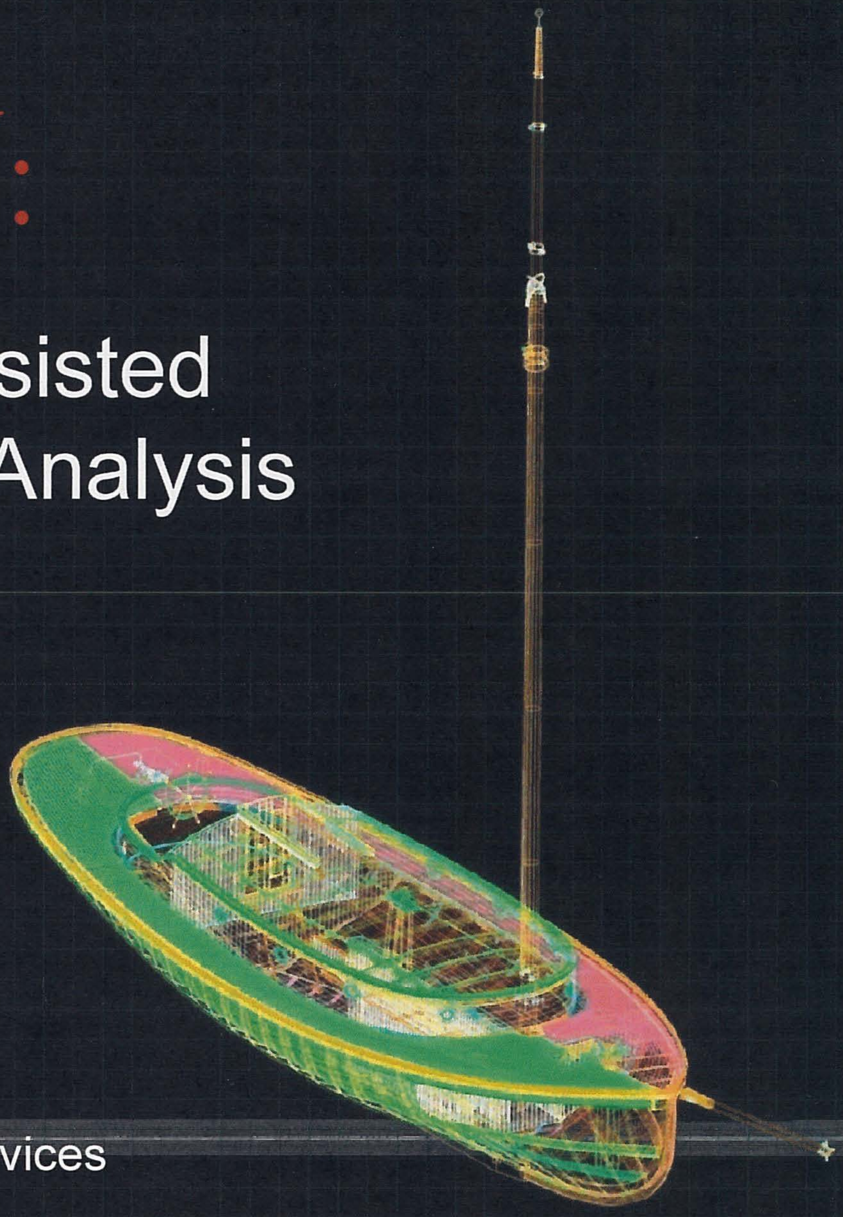
Draft 14 hull with corresponding Draft 12 of deck and toe rail Draft 4 superimposed on Scott's photo no. 365.



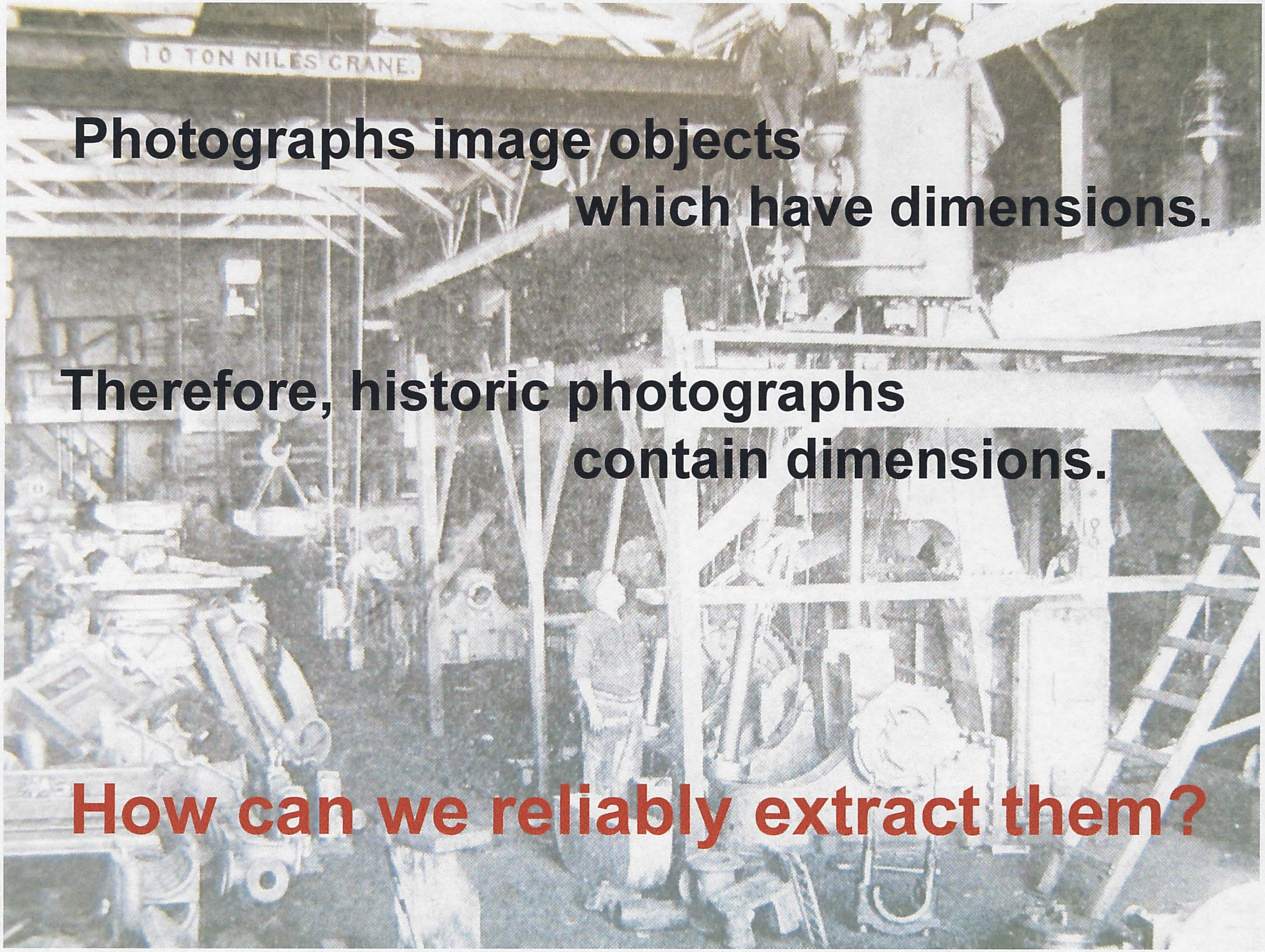
Draft 14 "restored" hull exported for camera location of Walter Scott's photo no. 366.

Restoring KATHLEEN:

A Role for Digitally Assisted Reverse Perspective Analysis in 3D CAD



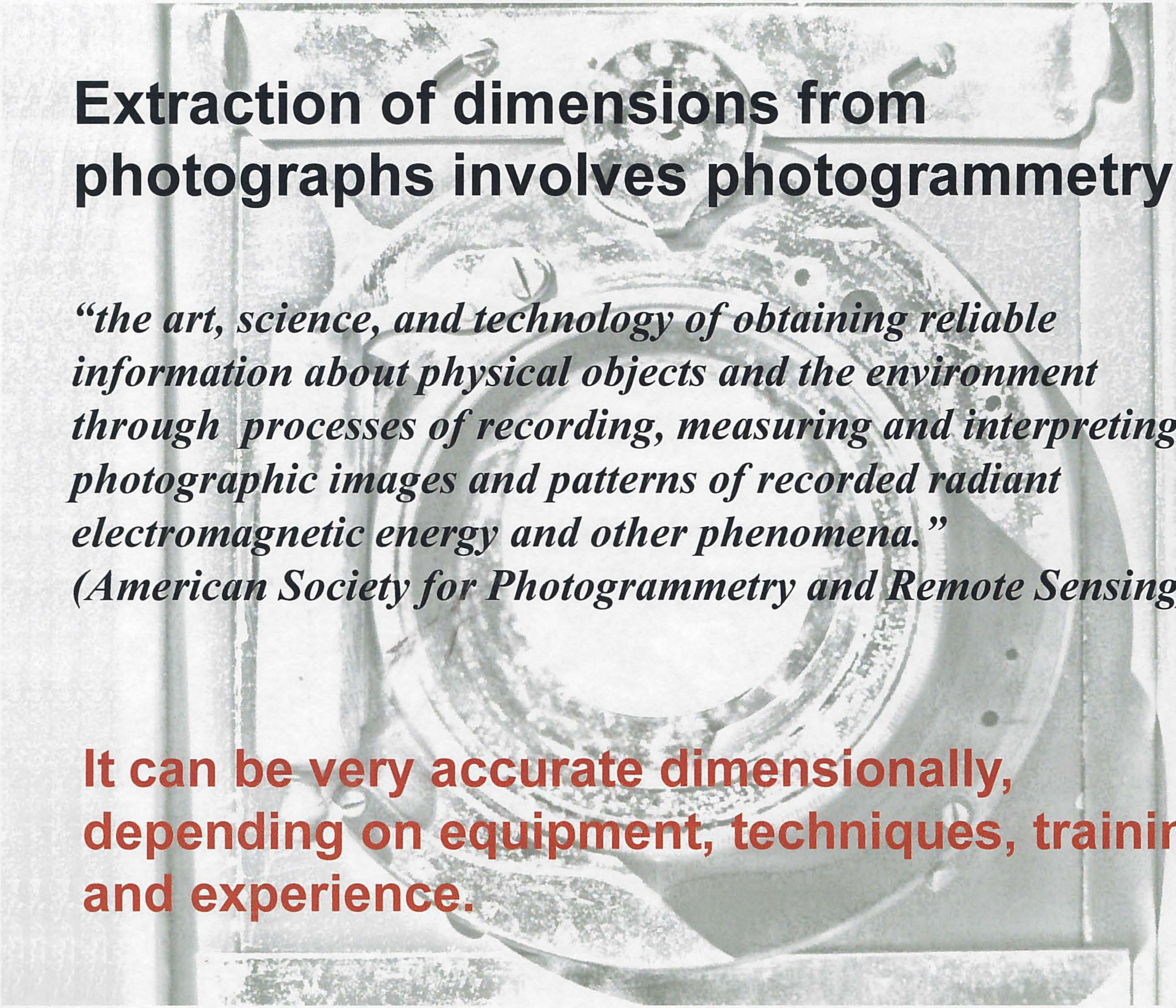
Richard K. Anderson, Jr.
Cultural Resource Documentation Services
Sumter, South Carolina



Photographs image objects
which have dimensions.

Therefore, historic photographs
contain dimensions.

How can we reliably extract them?



Extraction of dimensions from photographs involves photogrammetry--

"the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena."
(American Society for Photogrammetry and Remote Sensing)

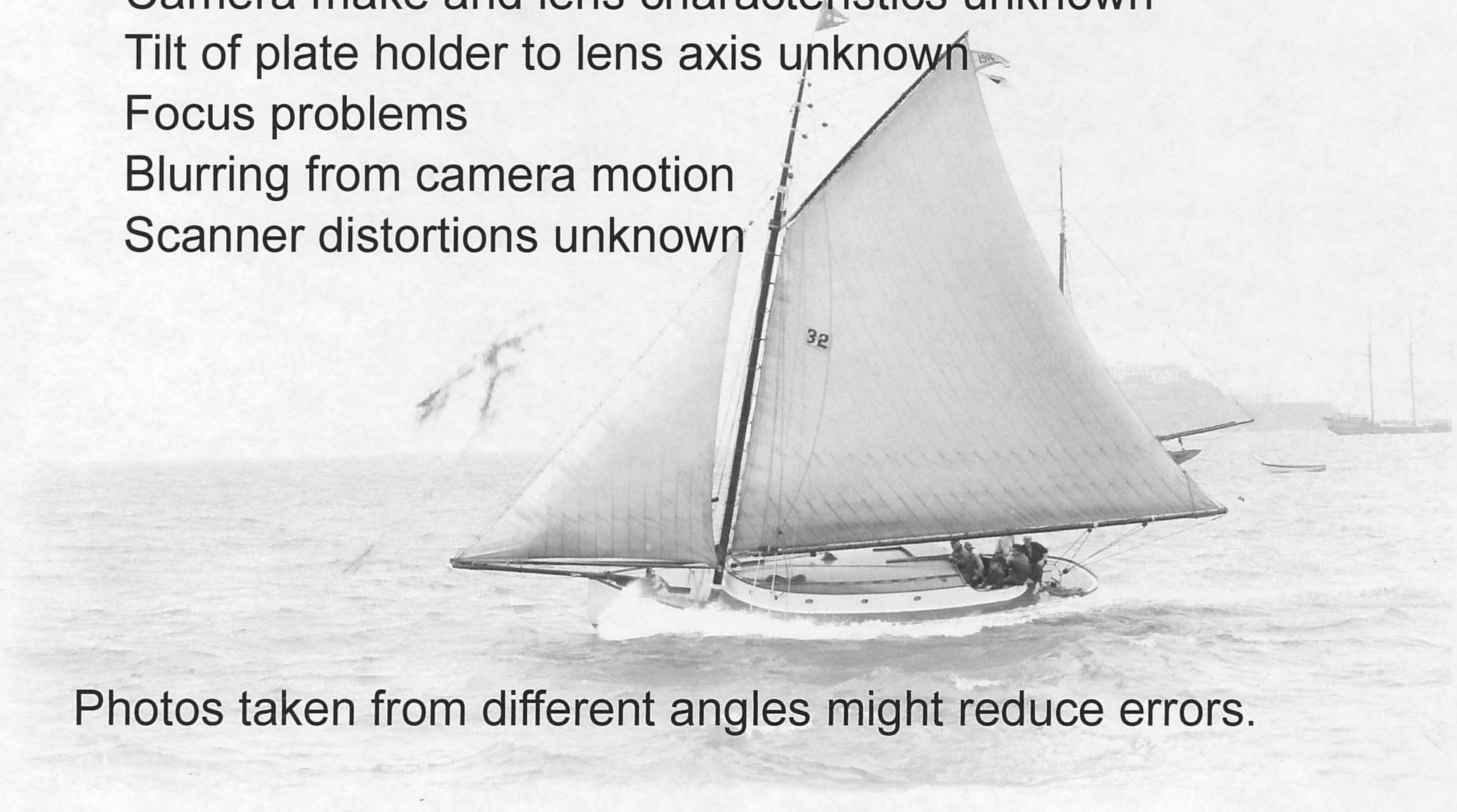
It can be very accurate dimensionally, depending on equipment, techniques, training and experience.

However,
most historic photographs and snapshots were not taken with any photogrammetric purposes in mind.

Numerous “unknowns” and defects complicate analysis:

- Camera type
- Focal length of lens
- Lens distortions
- Tilt of film plane to lens axis
- “Grain” of image (analogous to pixel resolution)
- Deterioration of emulsions and media
- Uneven dimensional changes in media
- Distortions in reproductions

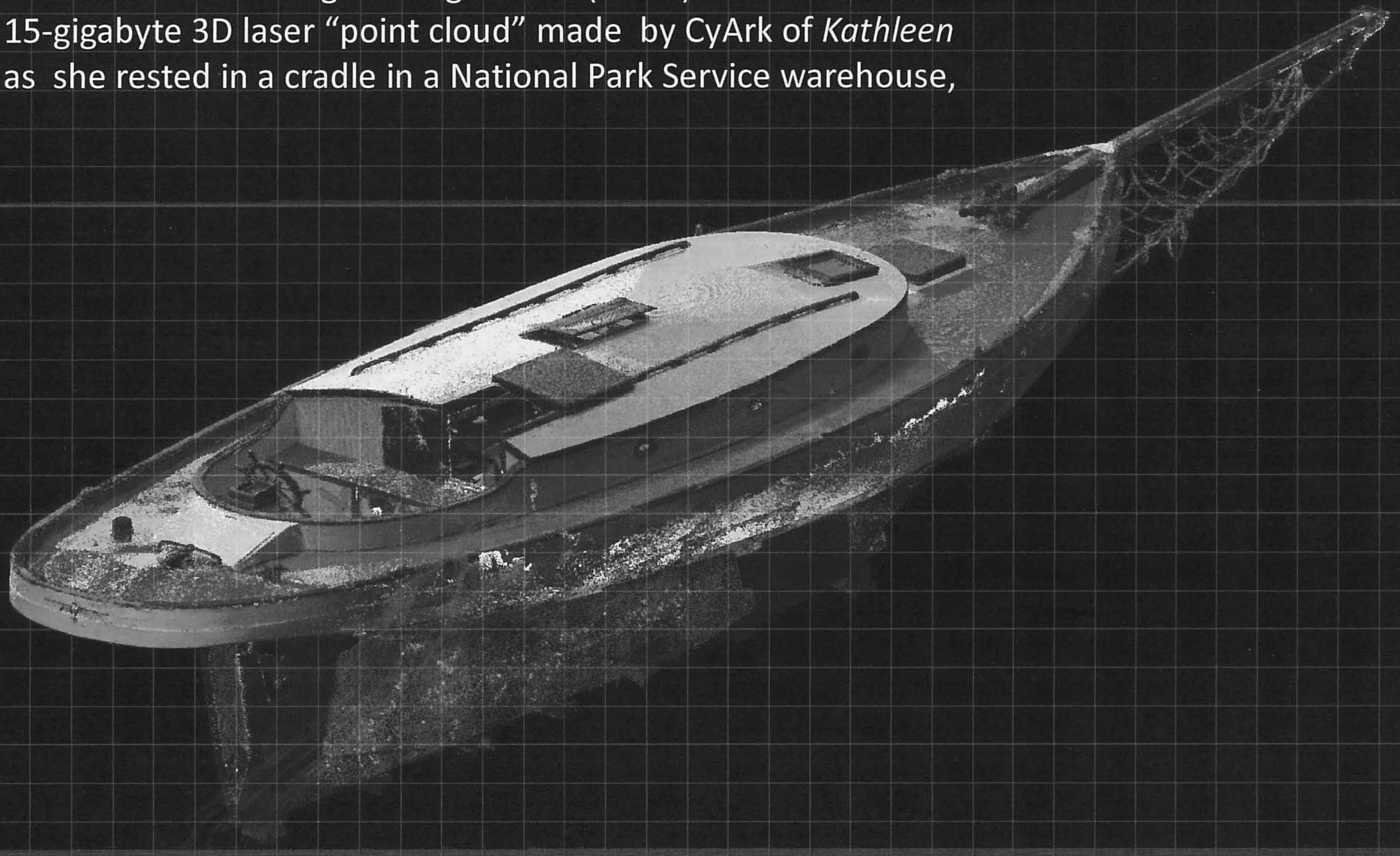
Nine Walter A. Scott photos of *Kathleen* taken ca. 1910:



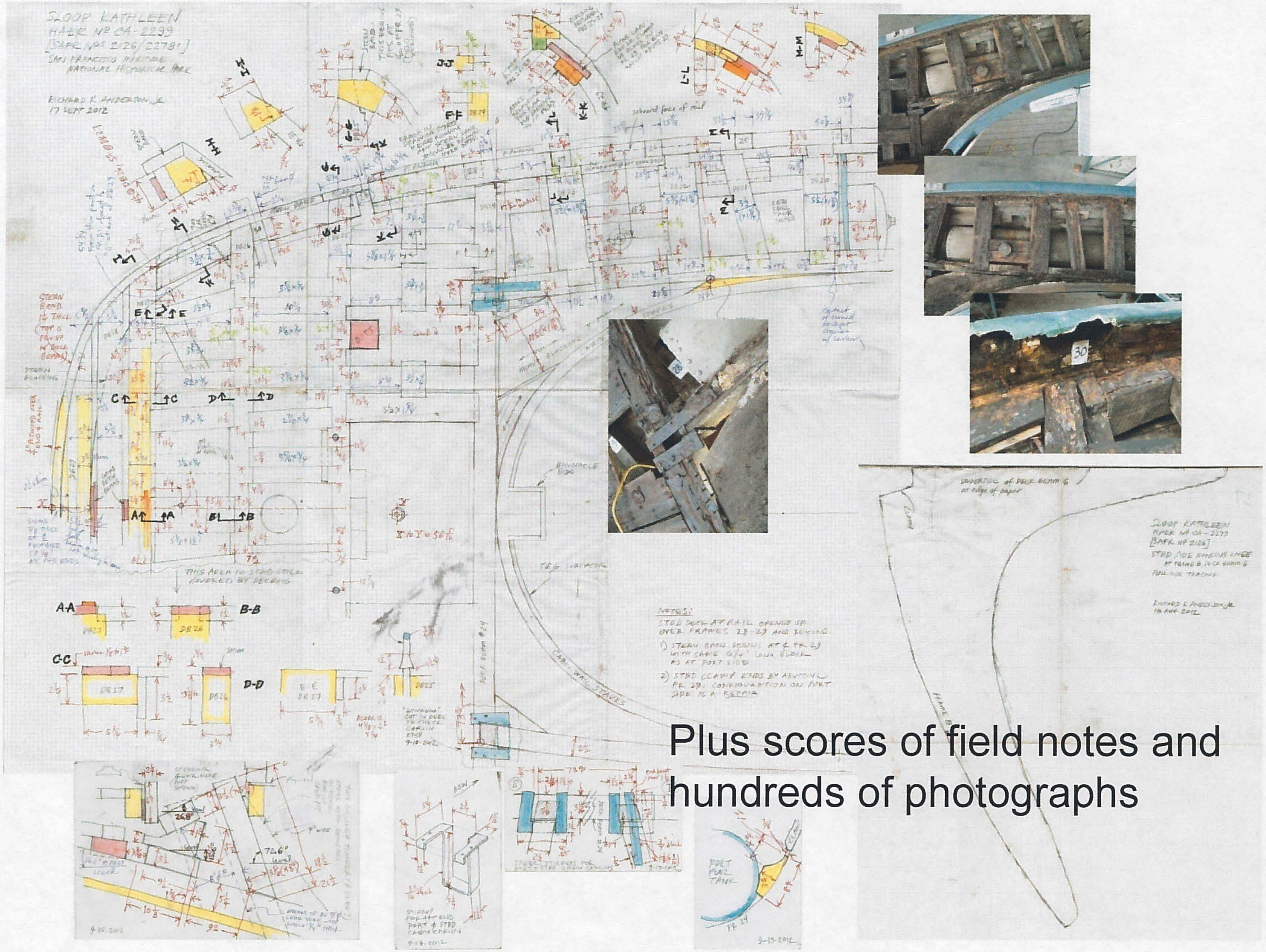
- 6½" x 8½" glass plate negatives, scanned at 600 dpi
- Camera make and lens characteristics unknown
- Tilt of plate holder to lens axis unknown
- Focus problems
- Blurring from camera motion
- Scanner distortions unknown

Photos taken from different angles might reduce errors.

The “as-is” documentation project conducted in 2012-2014 for the Historic American Engineering Record (HAER) was based on a 15-gigabyte 3D laser “point cloud” made by CyArk of *Kathleen* as she rested in a cradle in a National Park Service warehouse,



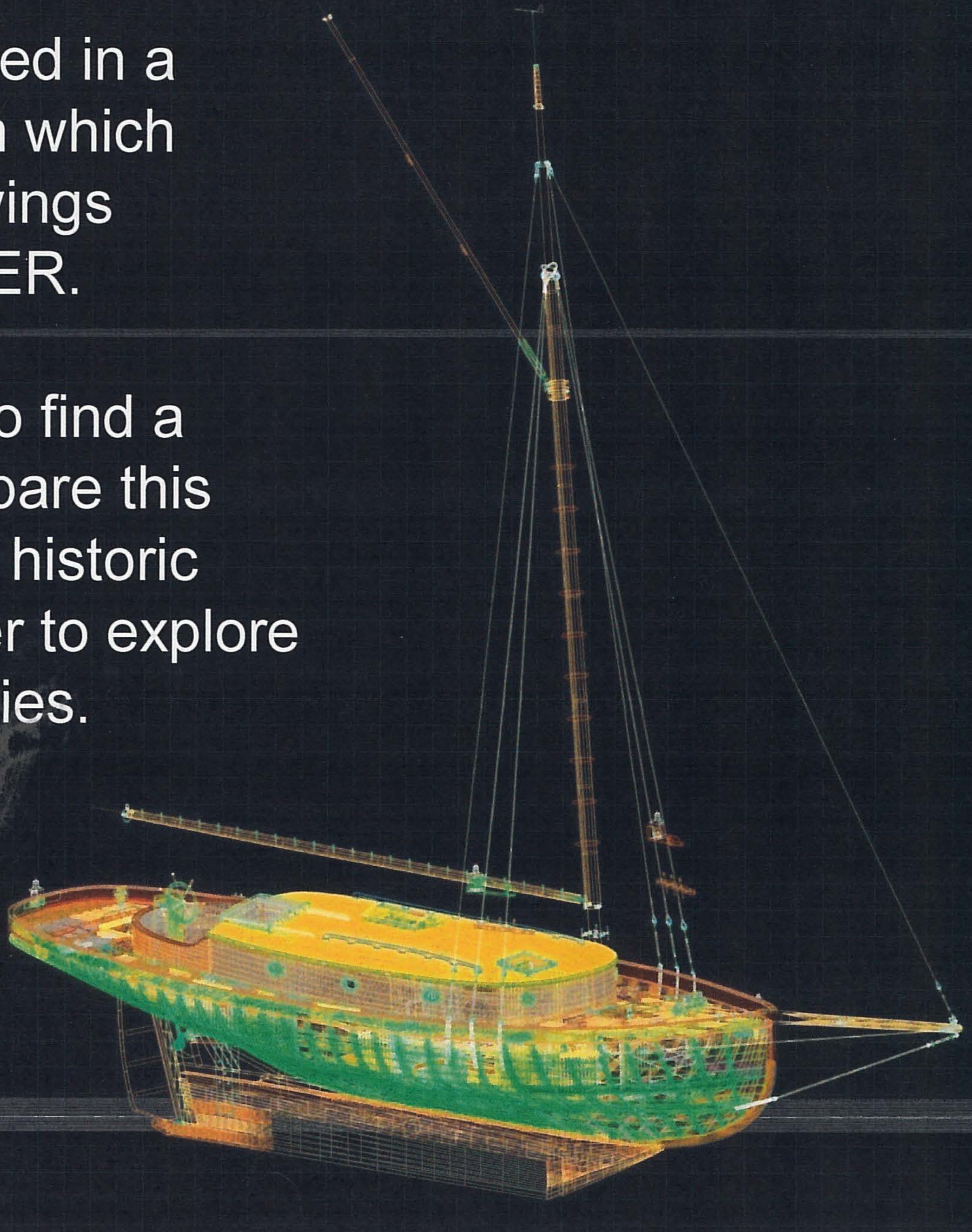
Plus --

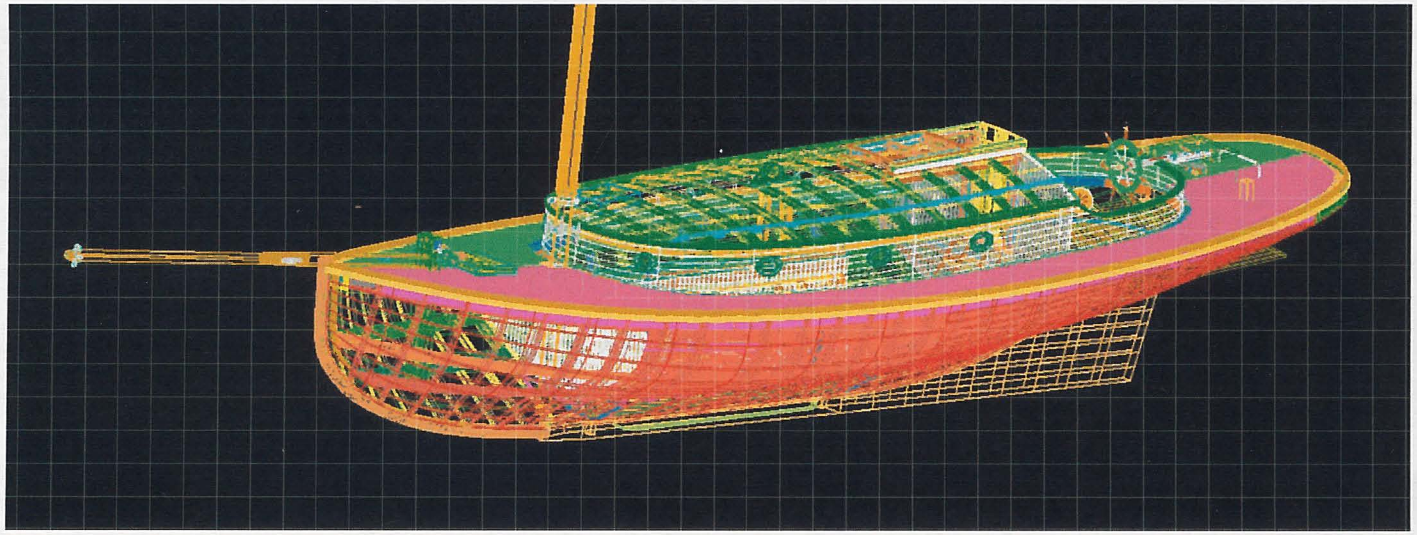


Plus scores of field notes and hundreds of photographs

The field data resulted in a 3D CAD model from which 10 detailed 2D drawings were plotted for HAER.

The next step was to find a reliable way to compare this 3D CAD model with historic photographs in order to explore restoration possibilities.



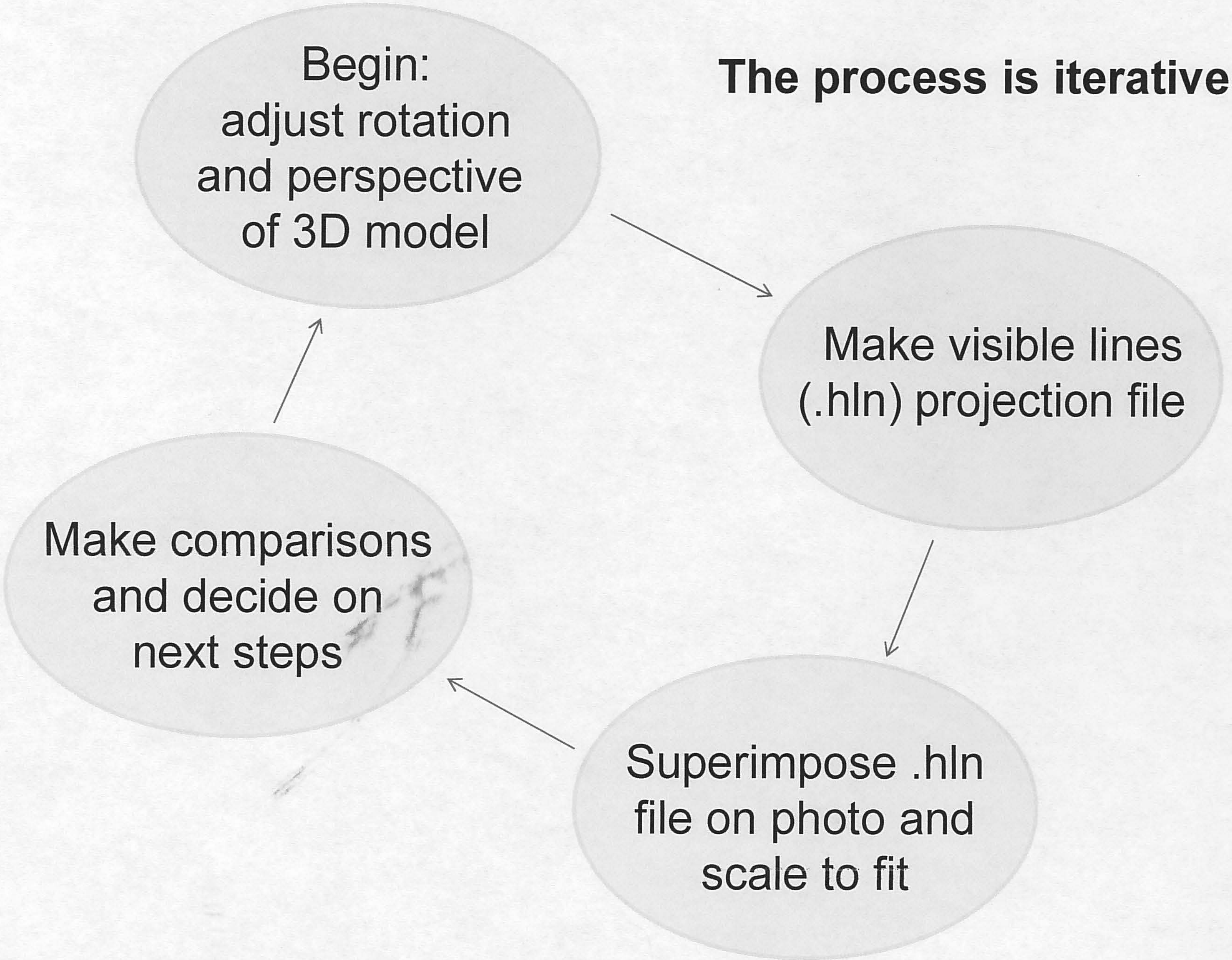


CAD has tools for taking 2D views of 3D models and superimposing them on historic photographs for comparative purposes.

In principle, I believed that
if a “restored” 3D CAD model of ***Kathleen*** were
accurately constructed, then projections from
that model should fit very closely over *any* historical
photographs from her early years,
regardless of their vantage points.

(Exceptions may be due to lens distortions,
image focus and blur, scanning errors
and so forth.)

The process is iterative:

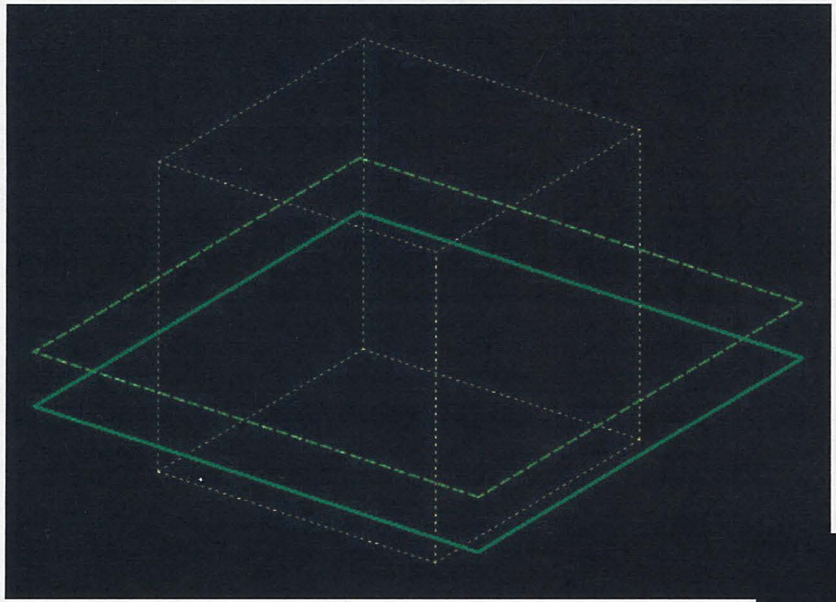


Begin: adjust rotation and perspective of 3D model

Make visible lines (.hln) projection file

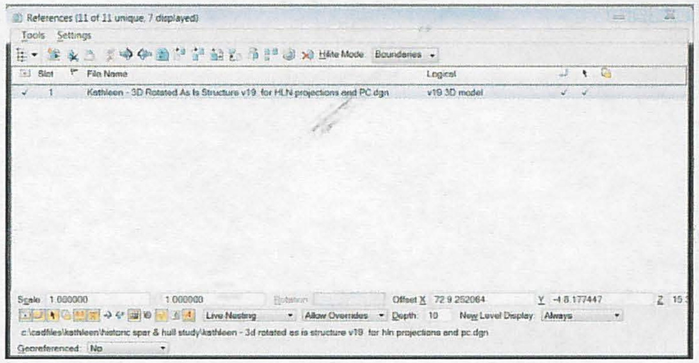
Superimpose .hln file on photo and scale to fit

Make comparisons and decide on next steps



A 3D file was set up for each of seven of the Walter Scott photos, all containing a 65-foot cube and planes representing the photo horizon and water's surface

Using CAD's reference file tool, the "as-is" 3D model was displayed inside the cube



References (11 of 11 unique, 7 displayed)

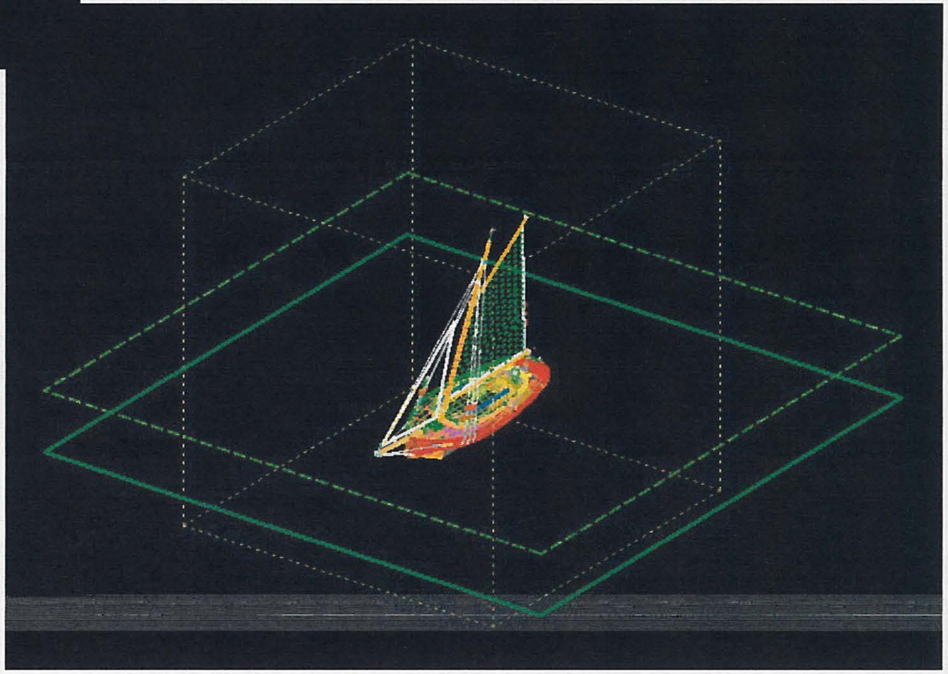
	Slot	File Name	Logical		
✓	1	Kathleen - 3D Rotated As Is Structure v19 for HLN projections and PC.dgn	v19 3D model	✓	✓

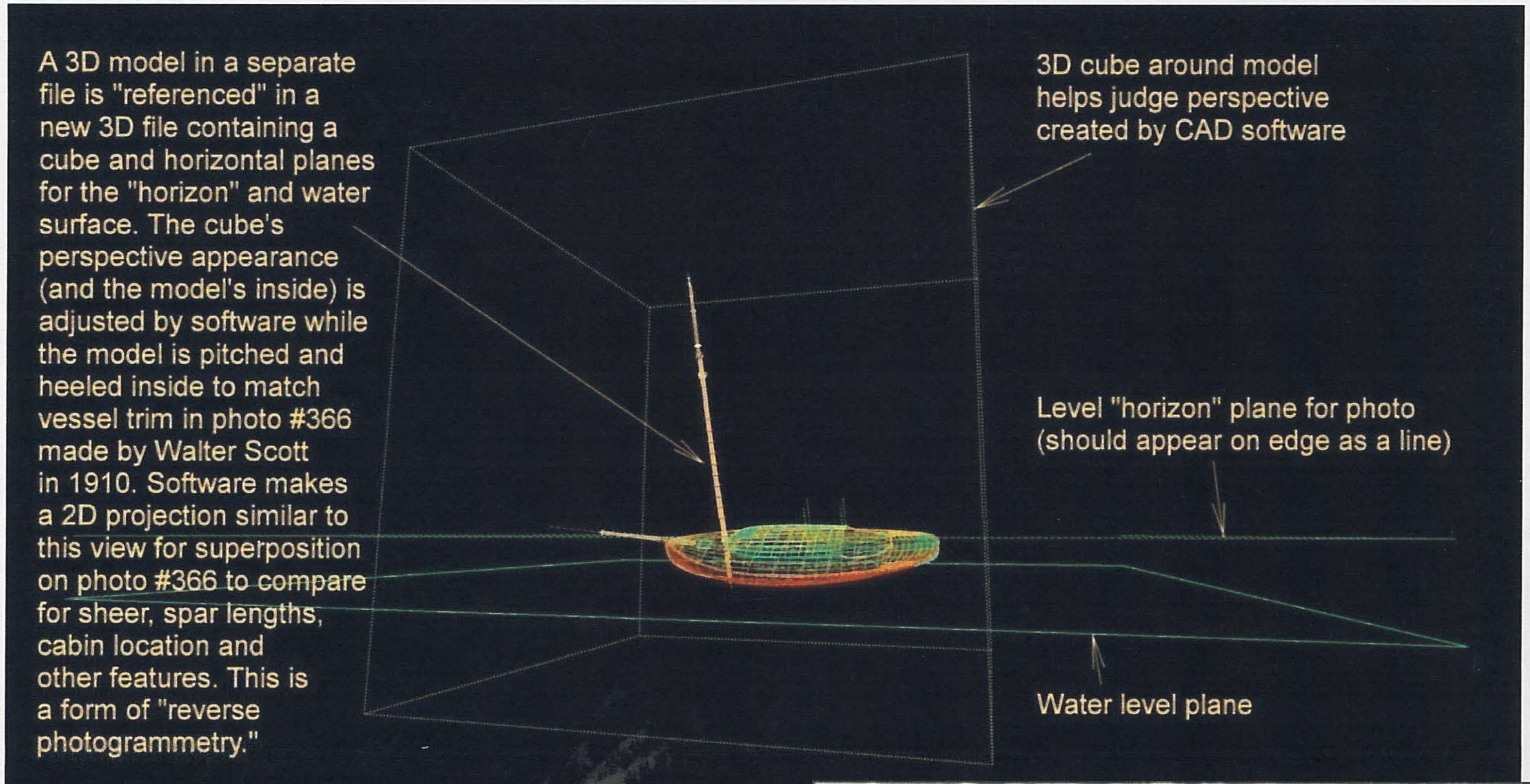
Scale 1.000000 1.000000 Offset X 729.252064 Y -48.177447 Z 15

Depth: 10 New Level Display: Always

c:\cadfiles\kathleen\historic spar & hull study\kathleen - 3d rotated as is structure v19 for hln projections and pc.dgn

Georeferenced: No





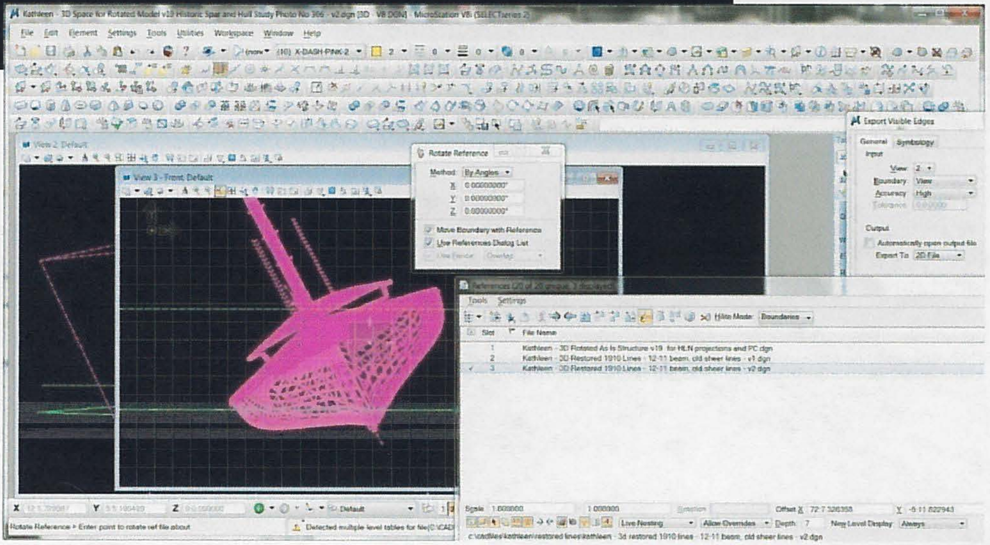
A 3D model in a separate file is "referenced" in a new 3D file containing a cube and horizontal planes for the "horizon" and water surface. The cube's perspective appearance (and the model's inside) is adjusted by software while the model is pitched and heeled inside to match vessel trim in photo #366 made by Walter Scott in 1910. Software makes a 2D projection similar to this view for superposition on photo #366 to compare for sheer, spar lengths, cabin location and other features. This is a form of "reverse photogrammetry."

3D cube around model helps judge perspective created by CAD software

Level "horizon" plane for photo (should appear on edge as a line)

Water level plane

The 3D model of *Kathleen* could then be rotated – pitch, roll, and yaw – to better approximate the boat's aspect in any one Walter Scott photograph.



Kathleen - 3D Space for Rotated Model v10 Historic Spar and Hull Study Photo No 366 - v2.dgn [3D - V8 DGN] - MicroStation V8i (SELECTseries 2)

Rotate Reference

Method: By Angles
X 0.00000000°
Y 0.00000000°
Z 0.00000000°
☑ Move Boundary with Reference
☑ Use References Dialog List

Input
View: 2
Boundary: View
Accuracy: High
Output
☐ Automatically open output file
Export To: 2D File

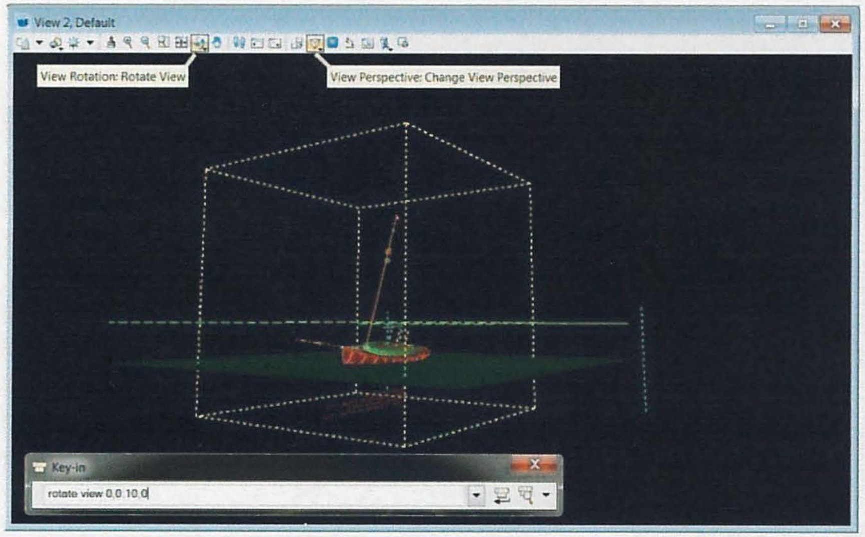
Hilite Mode: Boundaries

Slot	File Name
1	Kathleen - 3D Rotated As Is Structure v19 for HLN projections and PC.dgn
2	Kathleen - 3D Restored 1910 Lines - 12-11 beam, old sheer lines - v1.dgn
✓ 3	Kathleen - 3D Restored 1910 Lines - 12-11 beam, old sheer lines - v2.dgn

Scale 1.000000 1.000000
Offset X 72.7.326358 Y -6.11.822943
Live Nesting
Allow Overrides
Depth 7
New Level Display Always
c:\cadfiles\kathleen\restored lines\kathleen - 3d restored 1910 lines - 12-11 beam, old sheer lines - v2.dgn

Rotate Reference > Enter point to rotate ref file about

Detected multiple level tables for file(C:\CAD

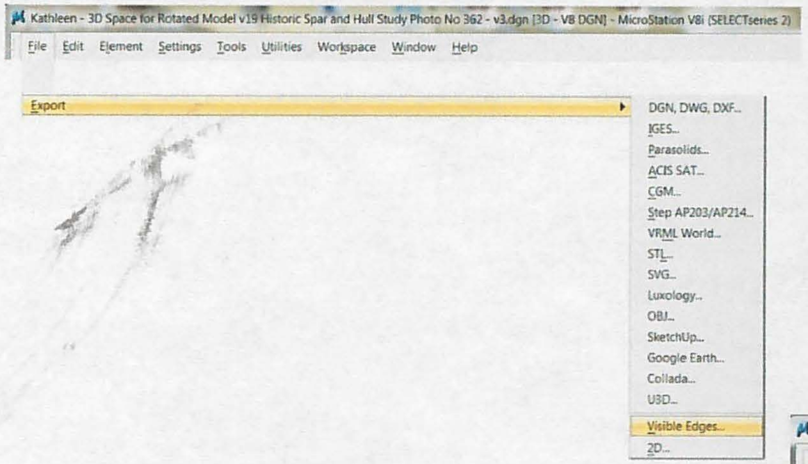

View 2, Default
View Rotation: Rotate View
View Perspective: Change View Perspective
Key-in

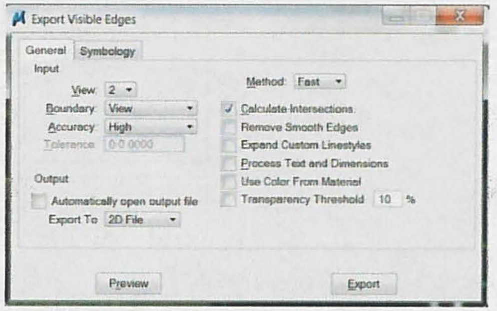
```
rotate view 0,0,10,0
```

CAD controls for rotating 3D models can be interactive or finely tuned

However, CAD controls for perspective are interactive only

Exporting a model's visible edges is fairly easy; there are many options:





Input

View: 2

Boundary: View

Accuracy: High

Tolerance: 0:0.0000

Method: Fast

☑ Calculate Intersections

☐ Remove Smooth Edges

☐ Expand Custom Linestyles

☐ Process Text and Dimensions

☐ Use Color From Material

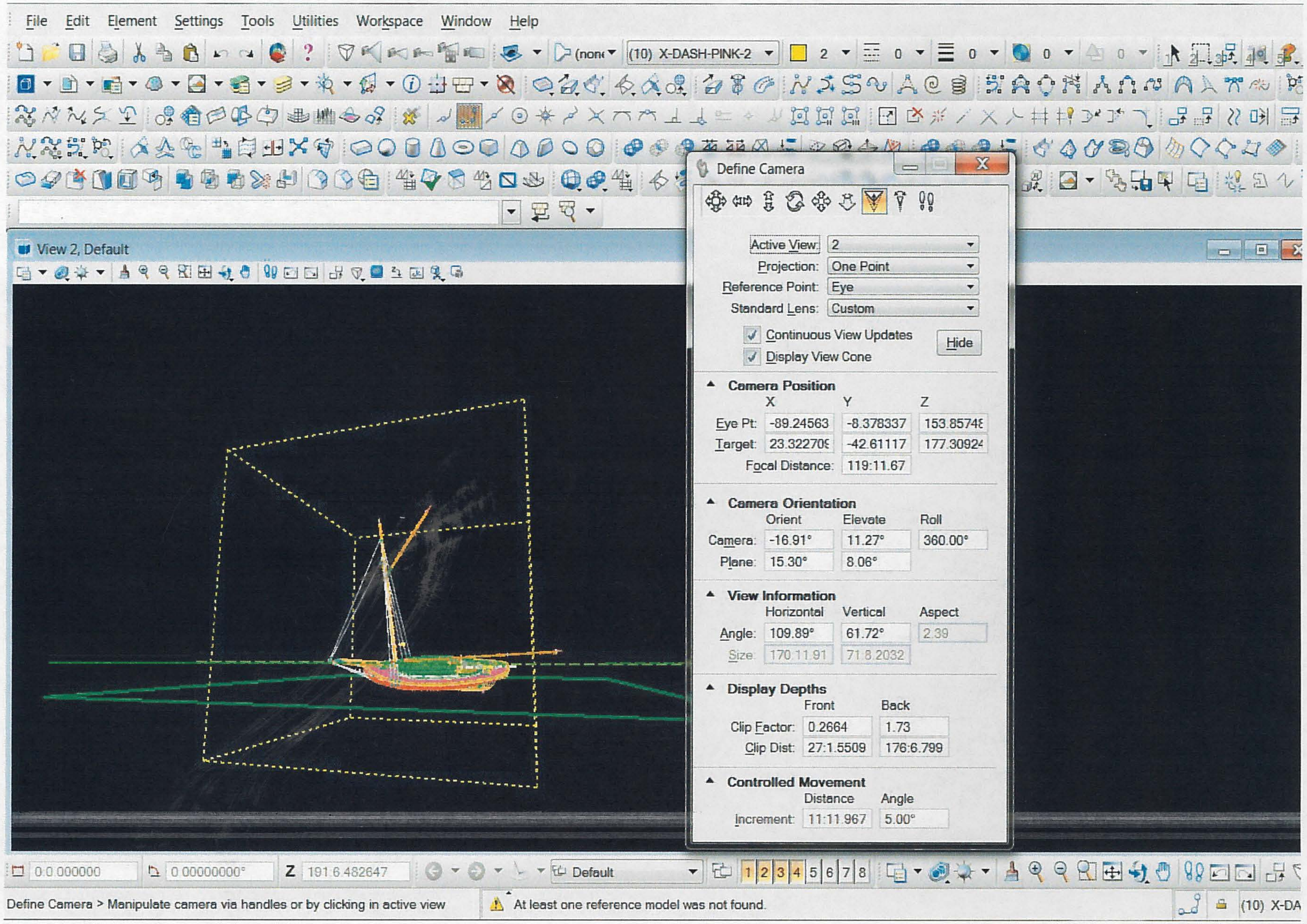
☐ Transparency Threshold 10 %

Output

☐ Automatically open output file

Export To: 2D File

CAD controls for “Camera” for each photo are listed and recorded for repeatability:



Active View: 2
Projection: One Point
Reference Point: Eye
Standard Lens: Custom

☑ Continuous View Updates
☑ Display View Cone

Camera Position

	X	Y	Z
Eye Pt:	-89.24563	-8.378337	153.85748
Target:	23.322709	-42.61117	177.30924
Focal Distance:		119:11.67	

Camera Orientation

	Orient	Elevate	Roll
Camera:	-16.91°	11.27°	360.00°
Plane:	15.30°	8.06°	

View Information

	Horizontal	Vertical	Aspect
Angle:	109.89°	61.72°	2.39
Size:	170:11.91	71:8.2032	

Display Depths

	Front	Back
Clip Factor:	0.2664	1.73
Clip Dist:	27:1.5509	176:6.799

Controlled Movement

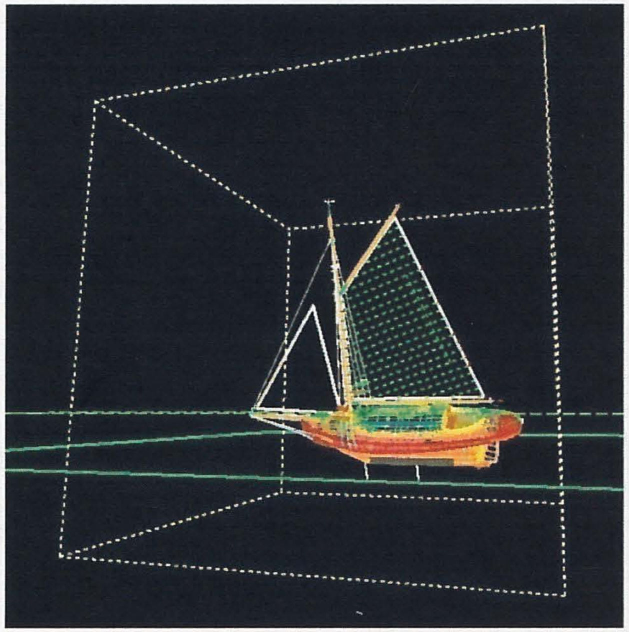
	Distance	Angle
Increment:	11:11.967	5.00°

0:0.000000 0.00000000° Z 191:6.482647 Default

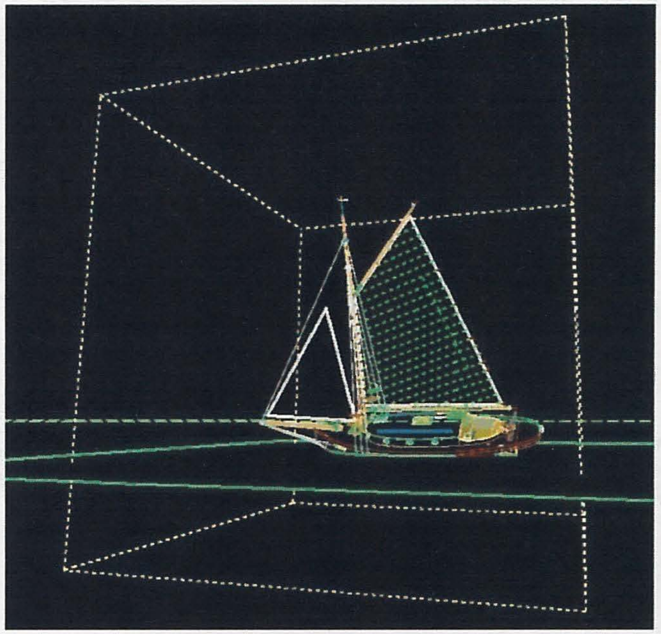
Define Camera > Manipulate camera via handles or by clicking in active view

At least one reference model was not found.

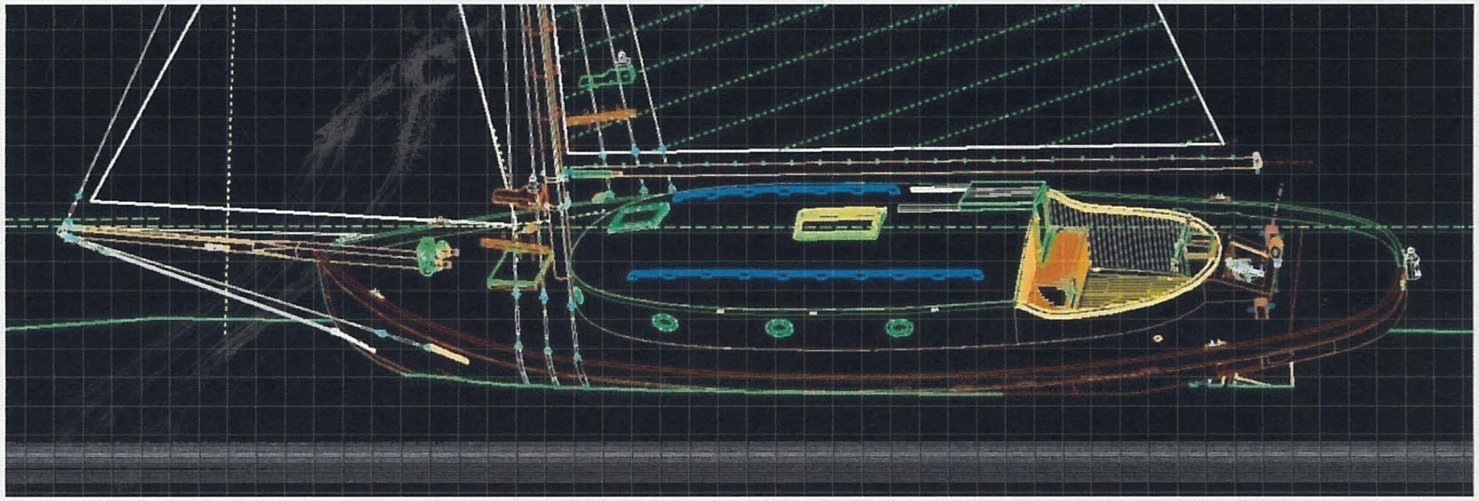
(10) X-DA



3D wireframe model ^

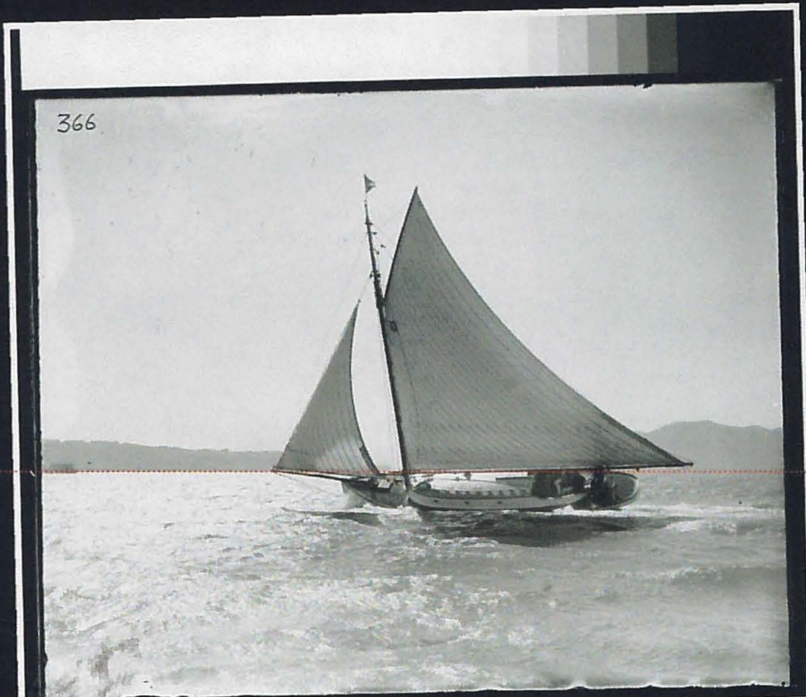


2D visible line projection^



There can be an extraordinary amount of detail in a visible line projection^

CAD can display photographs as “raster reference files”:



Kathleen (sloop: yacht) on San Francisco Bay, Calif., 1910. Photographed by Walter A. Scott. Photogs. No. 366. San Francisco Maritime National Historical Park, Walter A. Scott photographs, P83-019A 882g (SAFR 19105).

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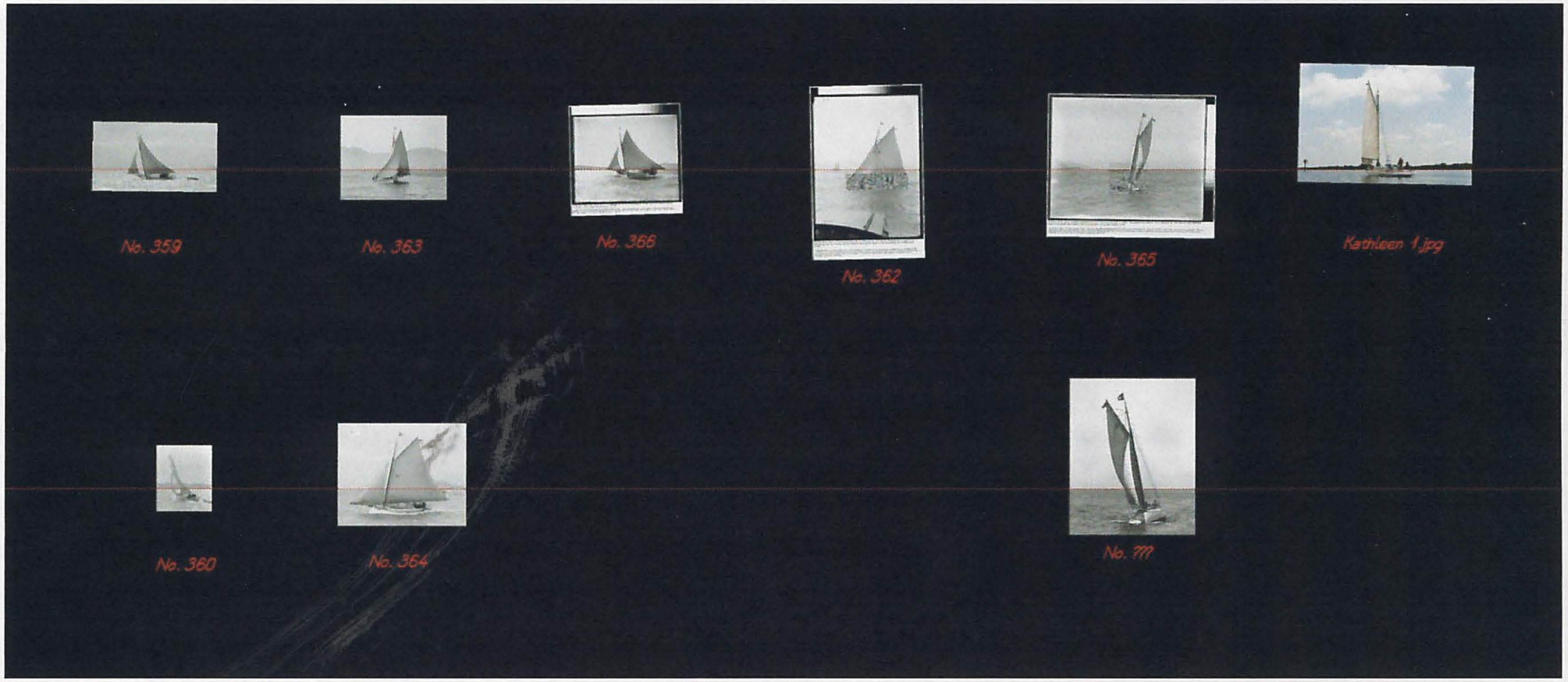
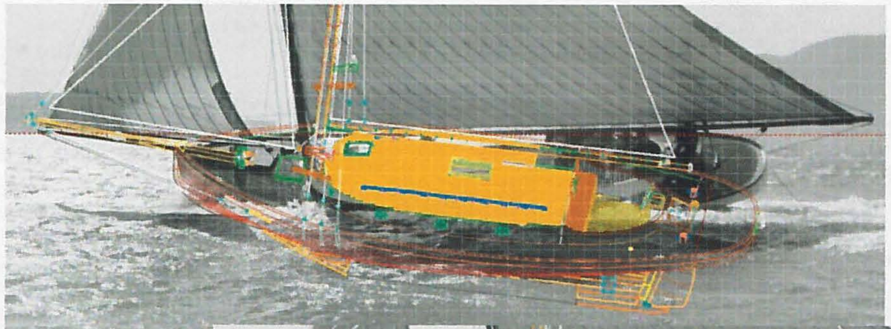
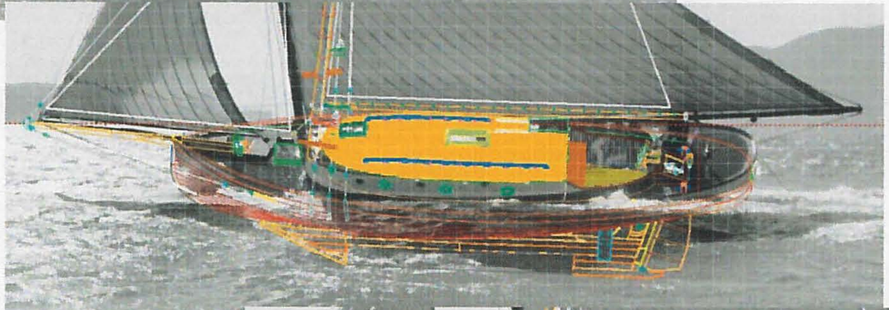
No. 366

I referenced all of Walter A. Scott's usable historic images of *Kathleen* to a single 2D CAD file and rotated them to a common horizon (or level line):

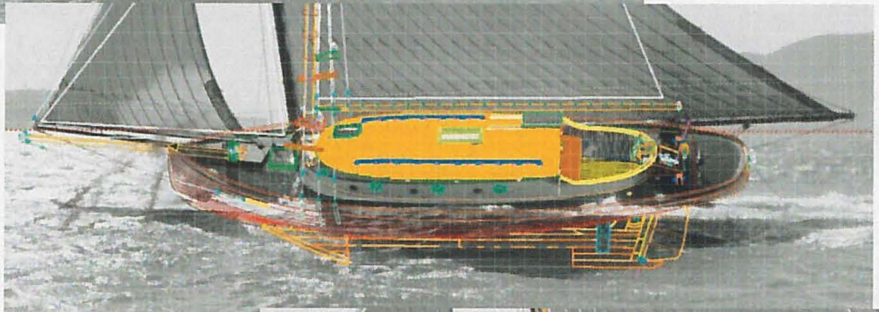


Trial 1 for “as-is” model over Photo 366

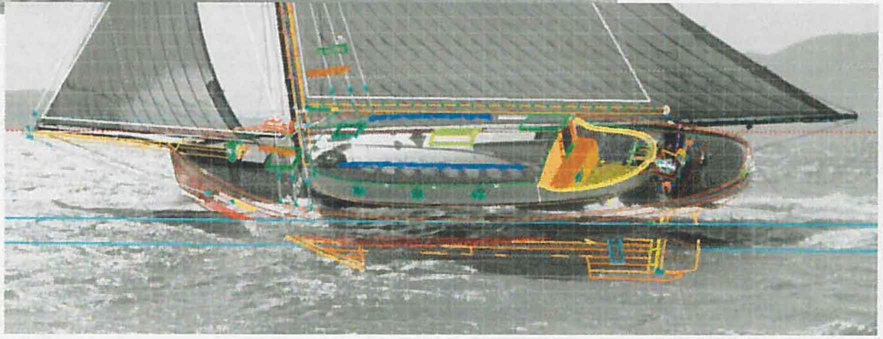




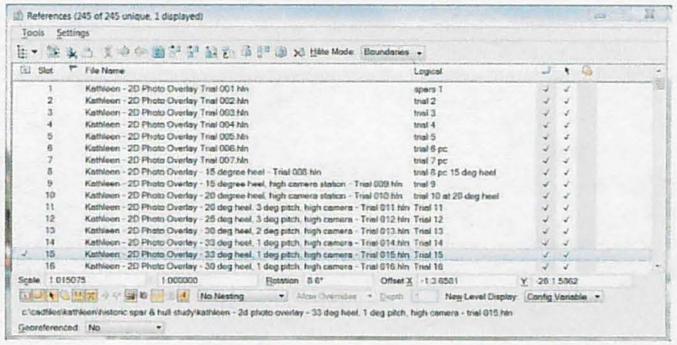
Trial 4



Trial 7



Trial 15



References (245 of 245 unique, 1 displayed)

	Slot	File Name	Logical		
	1	Kathleen - 2D Photo Overlay Trial 001.hln	spars 1	✓	✓
	2	Kathleen - 2D Photo Overlay Trial 002.hln	trial 2	✓	✓
	3	Kathleen - 2D Photo Overlay Trial 003.hln	trial 3	✓	✓
	4	Kathleen - 2D Photo Overlay Trial 004.hln	trial 4	✓	✓
	5	Kathleen - 2D Photo Overlay Trial 005.hln	trial 5	✓	✓
	6	Kathleen - 2D Photo Overlay Trial 006.hln	trial 6 pc	✓	✓
	7	Kathleen - 2D Photo Overlay Trial 007.hln	trial 7 pc	✓	✓
	8	Kathleen - 2D Photo Overlay - 15 degree heel - Trial 008.hln	trial 8 pc 15 deg heel	✓	✓
	9	Kathleen - 2D Photo Overlay - 15 degree heel, high camera station - Trial 009.hln	trial 9	✓	✓
	10	Kathleen - 2D Photo Overlay - 20 degree heel, high camera station - Trial 010.hln	trial 10 at 20 deg heel	✓	✓
	11	Kathleen - 2D Photo Overlay - 20 deg heel, 3 deg pitch, high camera - Trial 011.hln	Trial 11	✓	✓
	12	Kathleen - 2D Photo Overlay - 25 deg heel, 3 deg pitch, high camera - Trial 012.hln	Trial 12	✓	✓
	13	Kathleen - 2D Photo Overlay - 30 deg heel, 2 deg pitch, high camera - Trial 013.hln	Trial 13	✓	✓
	14	Kathleen - 2D Photo Overlay - 33 deg heel, 1 deg pitch, high camera - Trial 014.hln	Trial 14	✓	✓
✓	15	Kathleen - 2D Photo Overlay - 33 deg heel, 1 deg pitch, high camera - Trial 015.hln	Trial 15	✓	✓
	16	Kathleen - 2D Photo Overlay - 30 deg heel, 1 deg pitch, high camera - Trial 016.hln	Trial 16	✓	✓

Scale 1.015075 1.000000 Rotation 8.6° Offset X -13.6581 Y 261.5862

No Nesting

New Level Display: Config Variable

c:\cadfiles\kathleen\historic spar & hull study\kathleen - 2d photo overlay - 33 deg heel, 1 deg pitch, high camera - trial 015.hln

Georeferenced: No

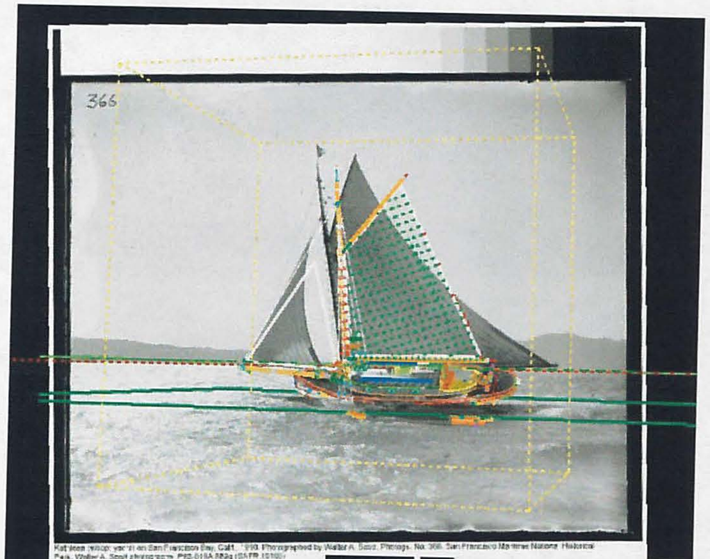


Photo 366,
< Trial 18

Severe hog became obvious after a number of trials

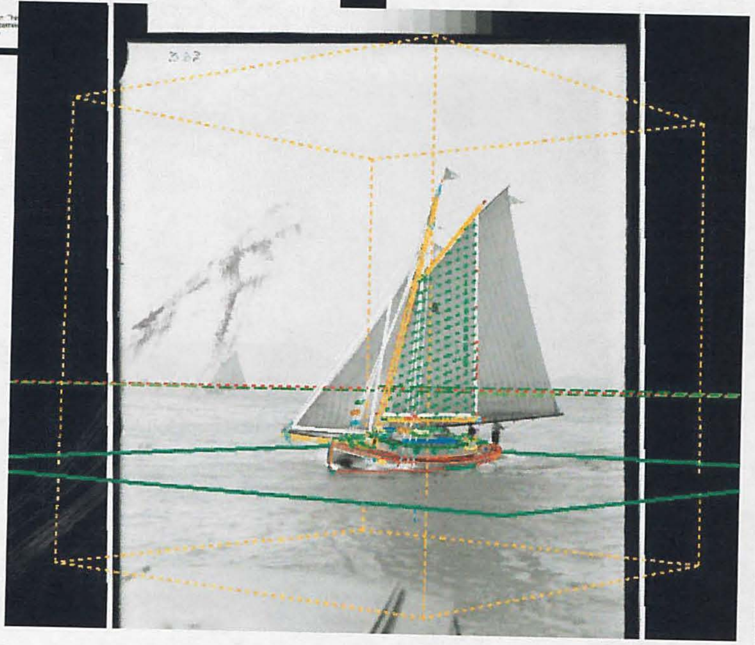


Photo 362
Trial 43 >

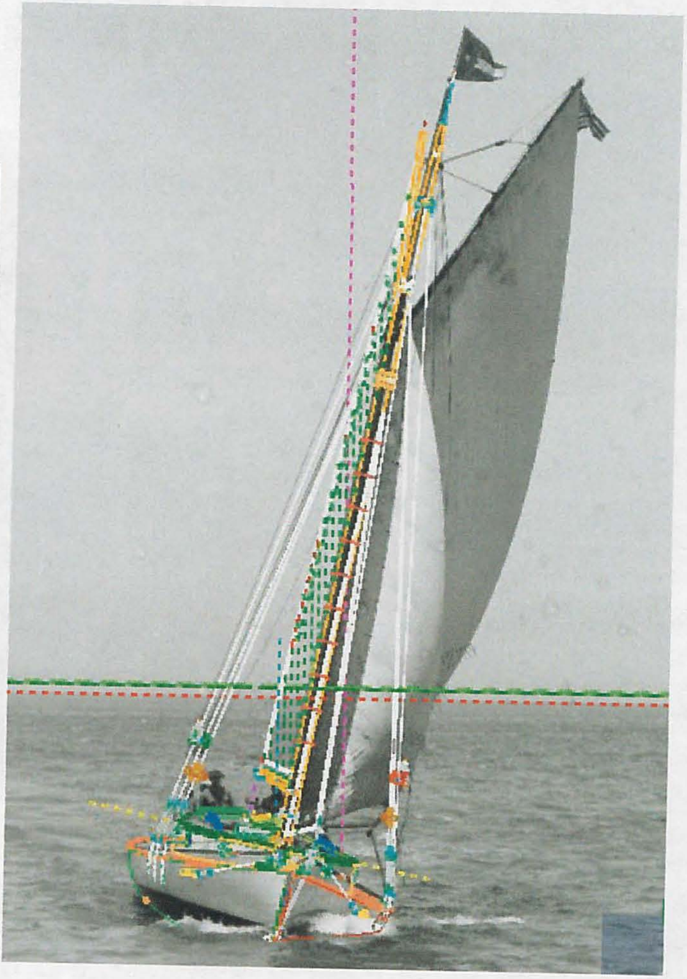
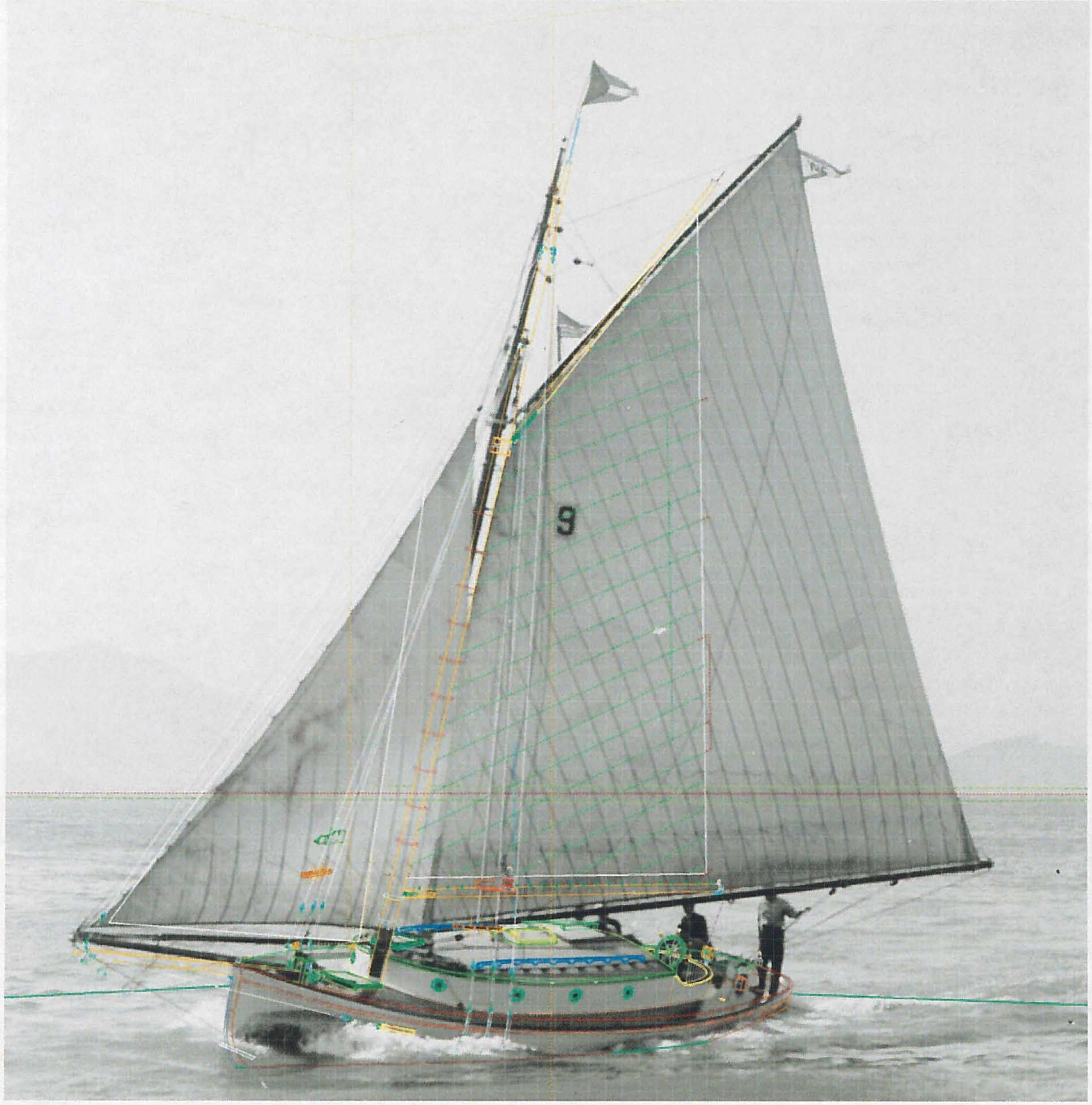
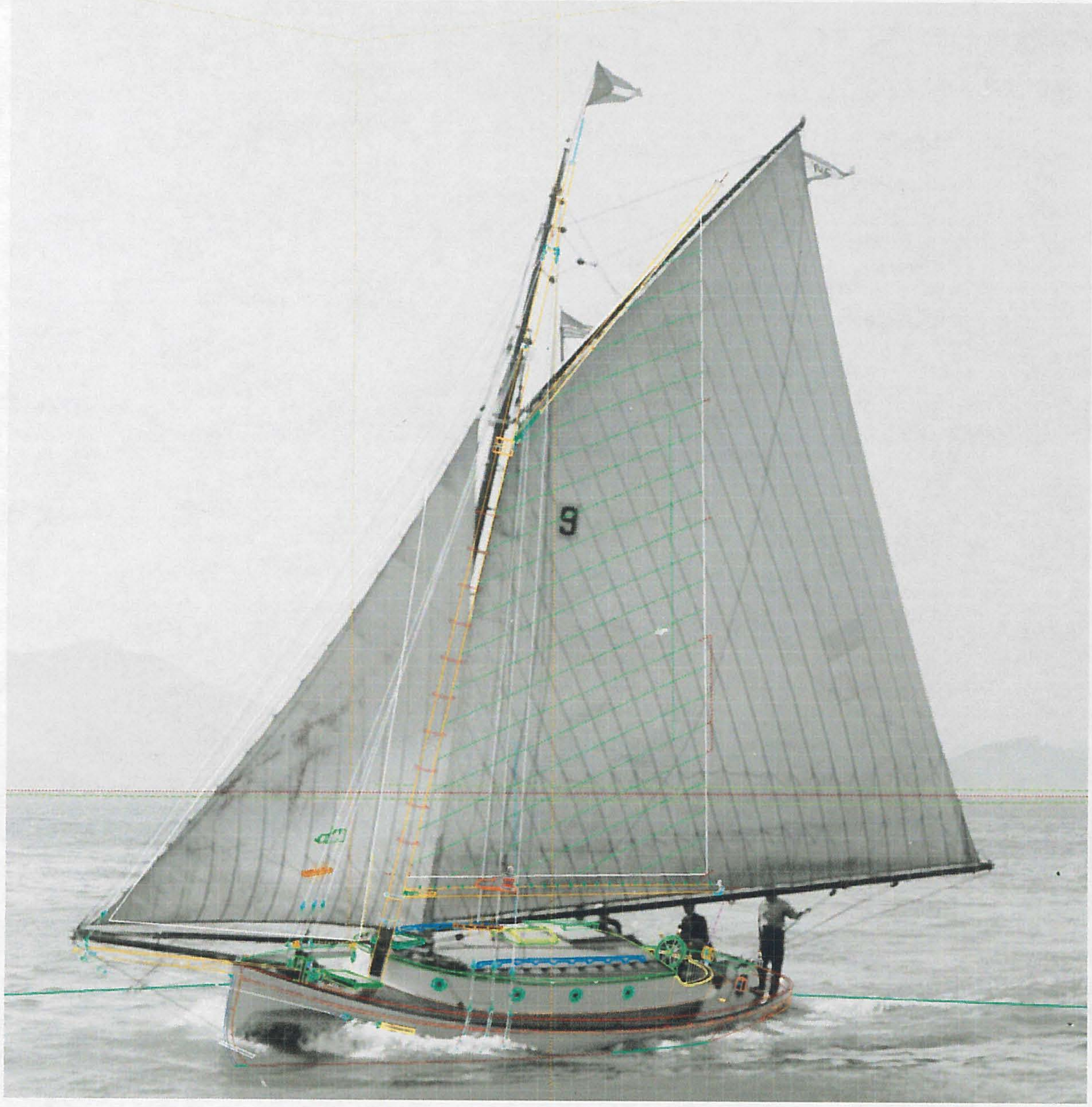


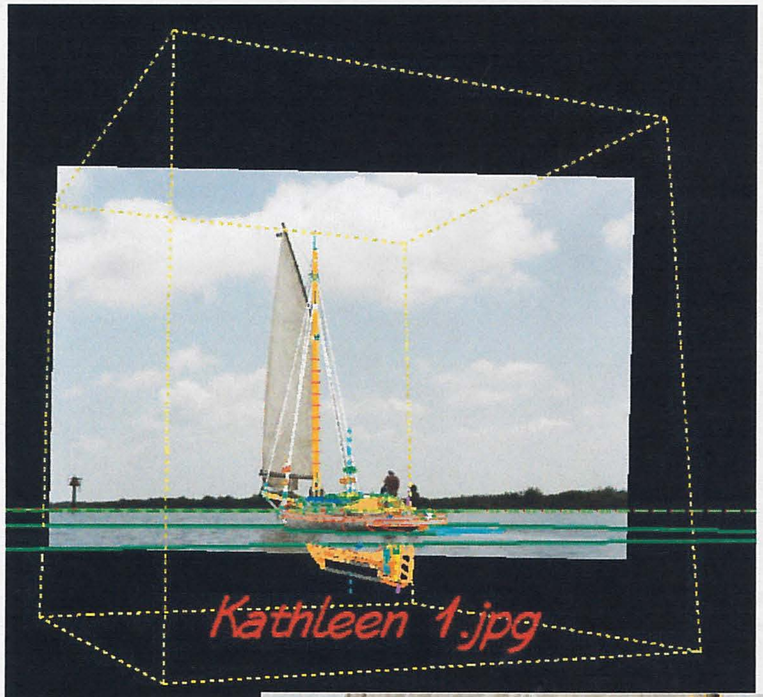
Photo 365, Trial 65 >



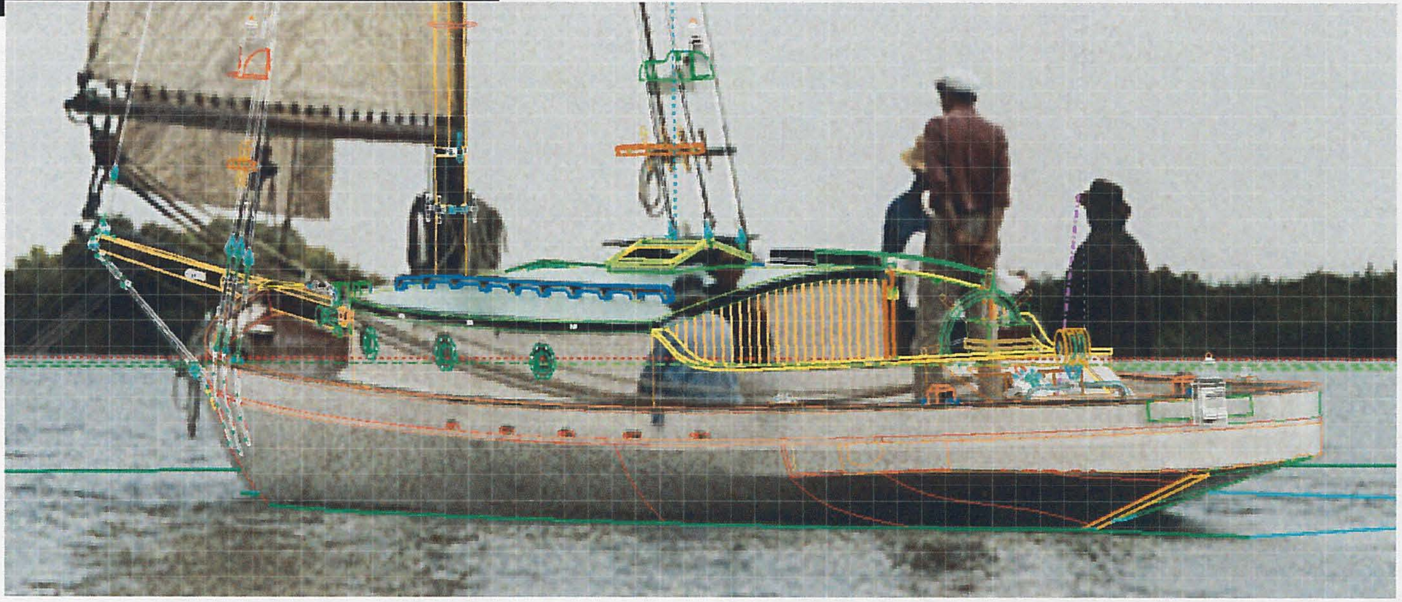
High-resolution screen shot of Photo 362, Trial 43



High-resolution screen shot of Photo 362, Trial 43



Superimposing the 2012 “as-is” model over a 1990s photo gives a very good match, however, so hogging probably stopped before this photo was taken.



There is no way to “bend” or “squish” the 2012 3D model of *Kathleen* in CAD so she returns to her 1904 shape.

To produce a 3D model that is true to *Kathleen*’s 1904 state means starting all over.

The first question is **“Where do we start?”**

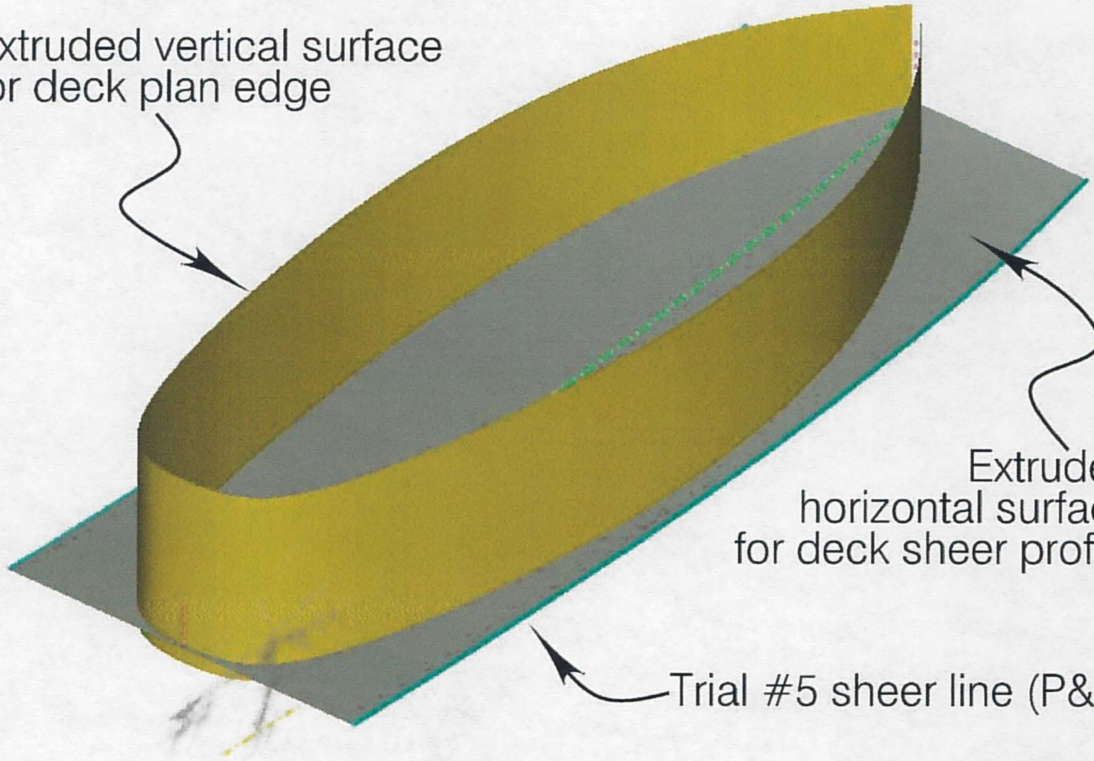
I decided to look at what *hasn’t* changed versus what has.

There being no historical evidence that *Kathleen* was lengthened or widened, I decided that the deck shape ***in plan*** was probably unchanged from 1904, while the deck sheer had obviously flattened.

In CAD I could erect a vertical surface that followed the deck outline and intersect it with several different sheer surfaces in profile. This would result in sheer outlines I could compare with Walter Scott’s photos, assuming no appreciable hog occurred between 1904 and 1910-11.

The question of hull shape (“lines”) would be secondary to the sheer.

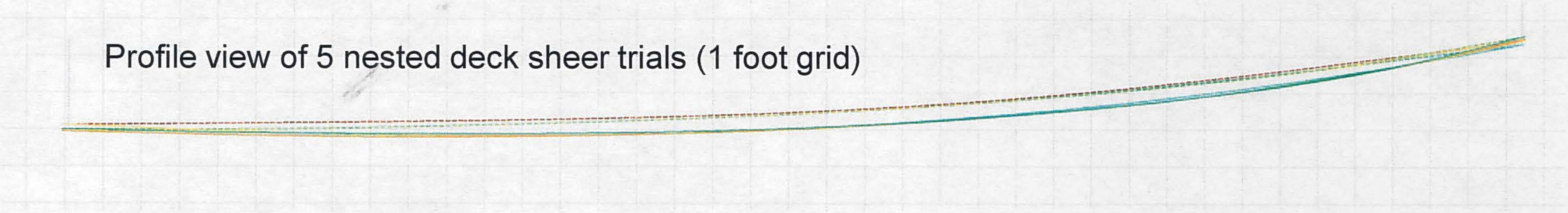
Steps in working out 1904 deck shape:



Extruded vertical surface for deck plan edge

Extruded horizontal surface for deck sheer profile

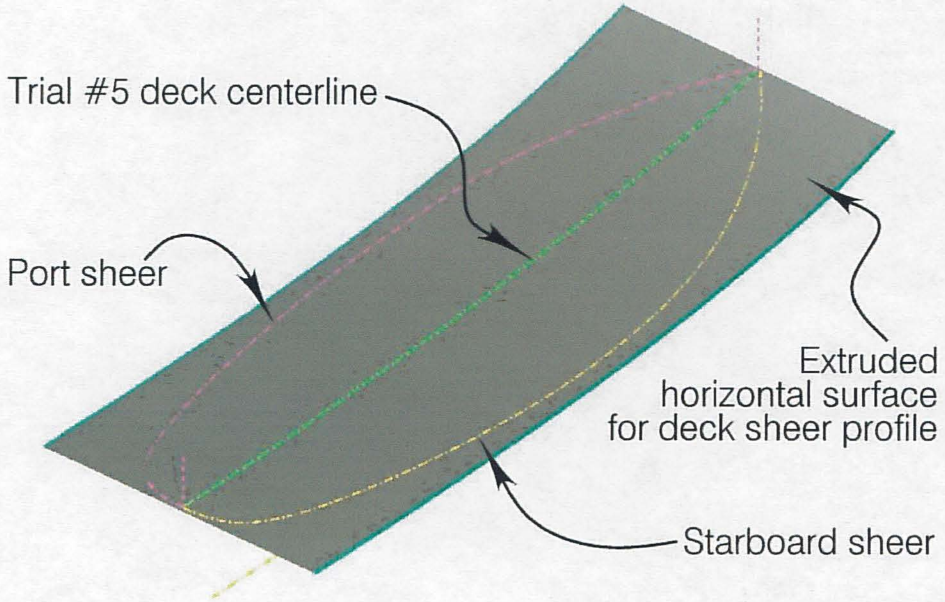
Trial #5 sheer line (P&S)

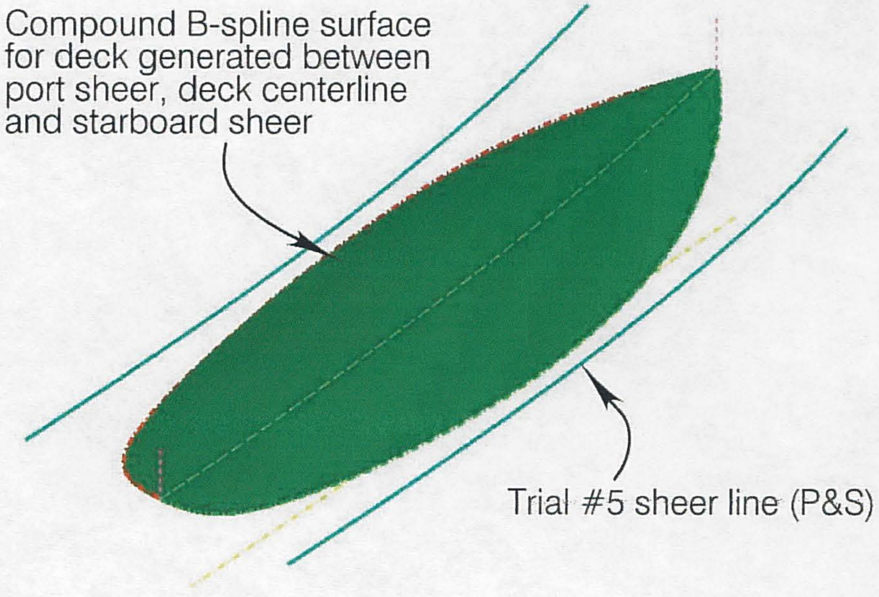


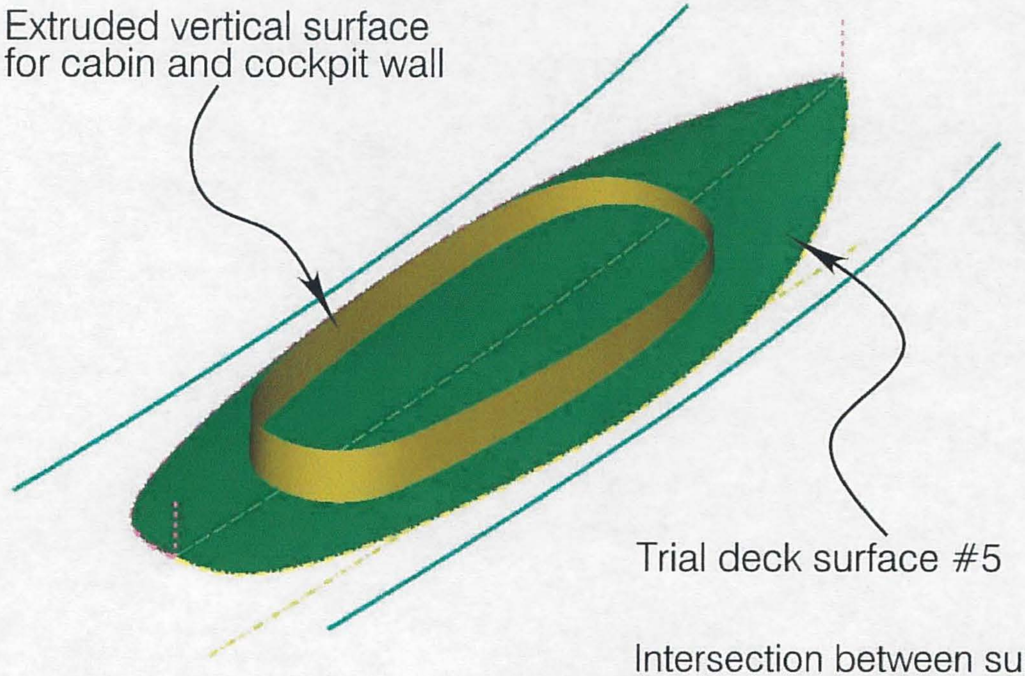
Profile view of 5 nested deck sheer trials (1 foot grid)

14 trial combinations of sheer and deck centerline were made to compare to photos

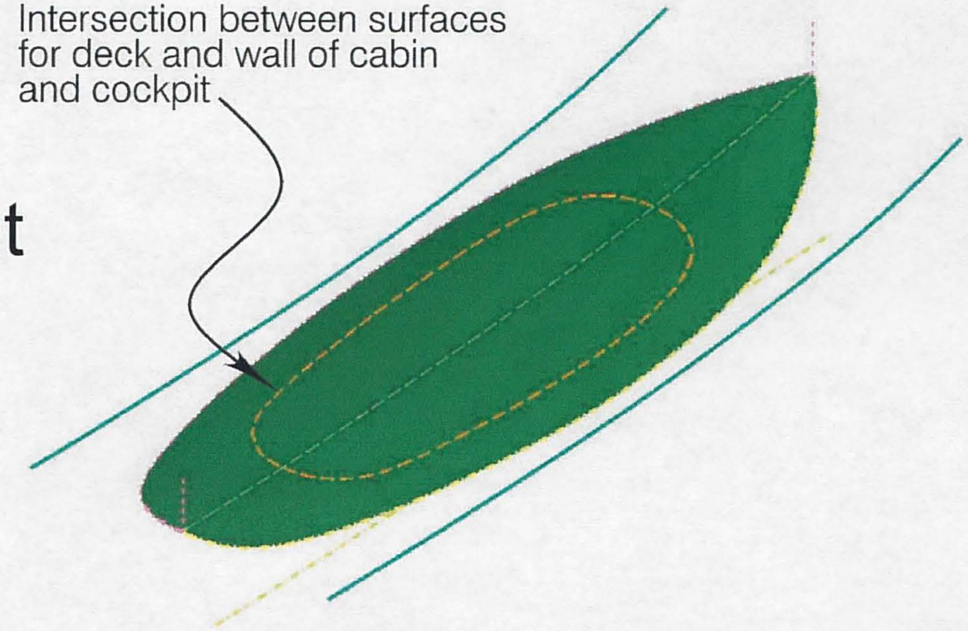
Steps in working out 1904 deck shape:




Compound B-spline surface for deck generated between port sheer, deck centerline and starboard sheer
Trial #5 sheer line (P&S)



Steps in working out 1904 deck shape:


Intersection between surfaces for deck and wall of cabin and cockpit

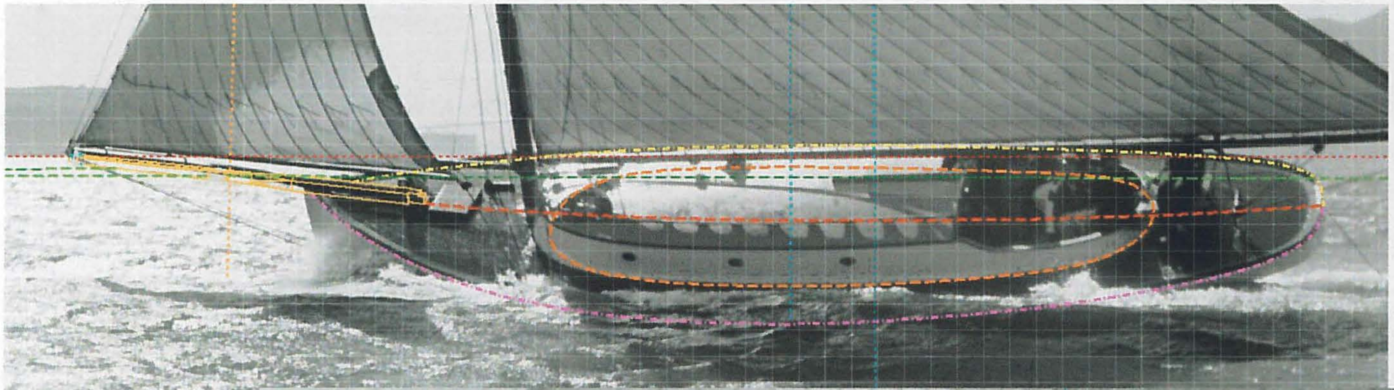


Photo 366
Deck #9
Trial 130

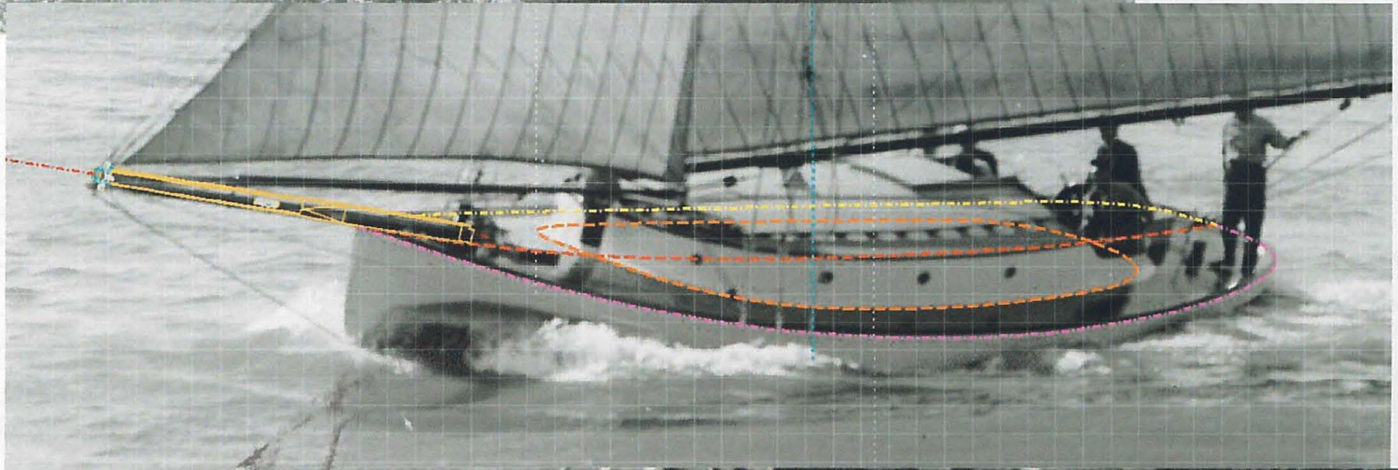


Photo 362
Deck #9
Trial 123

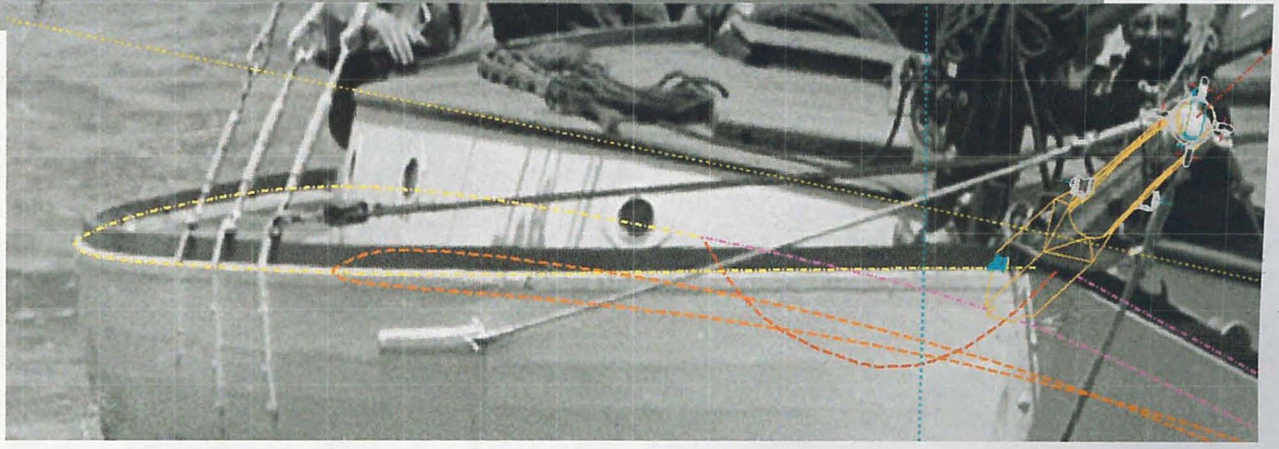
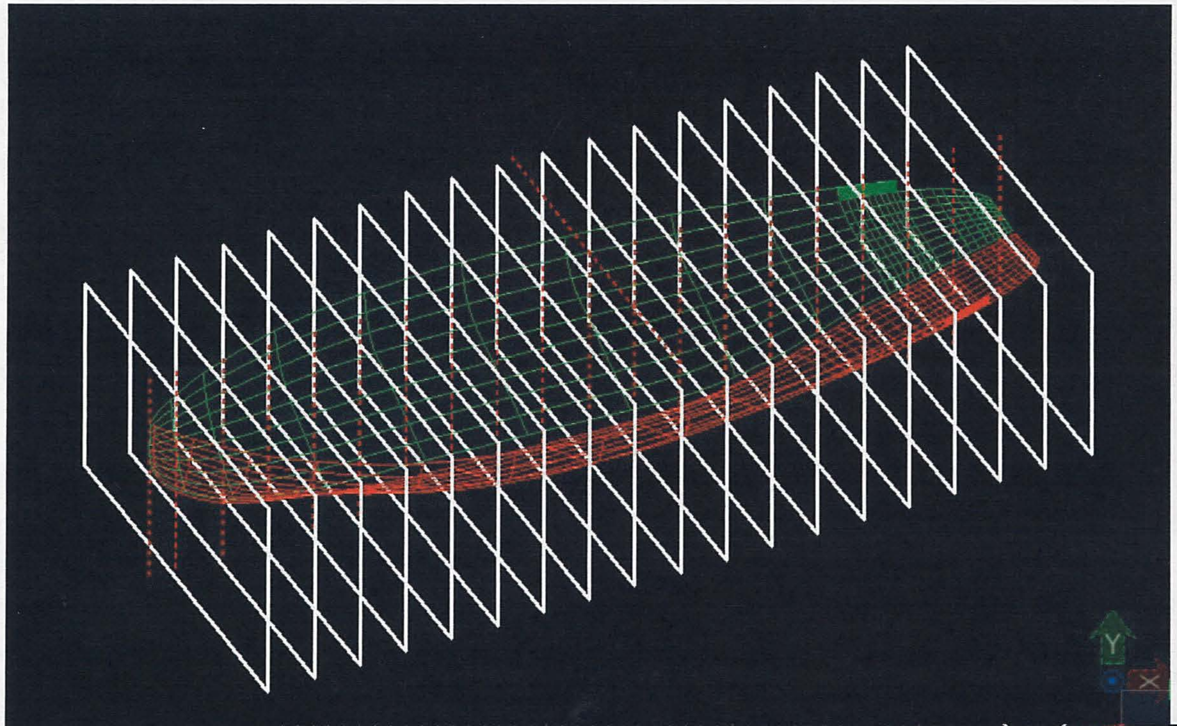
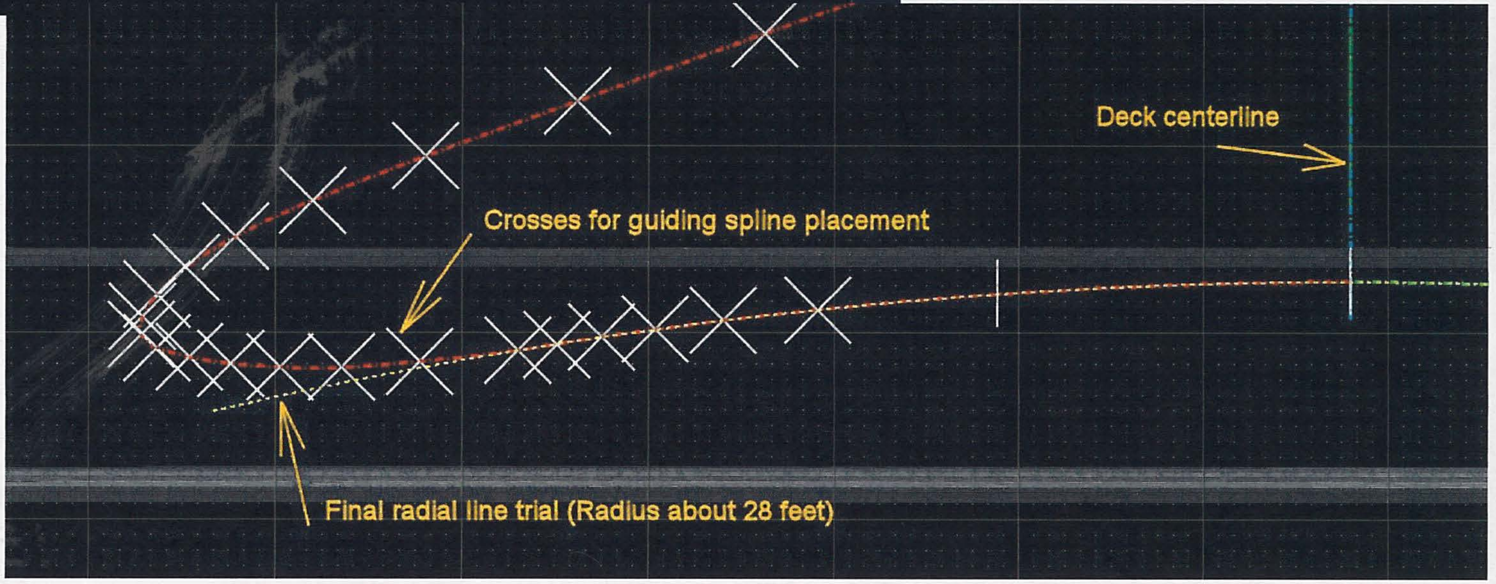


Photo 365
Deck #9
Trial 125



2012 hull surfaces sectioned by transverse planes spaced on 2-foot centers; crosses placed along P&S sheer for Deck #10 (1904) Where sheer intersected planes.

Deck camber at stern finally resolved


Deck centerline
Crosses for guiding spline placement
Final radial line trial (Radius about 28 feet)

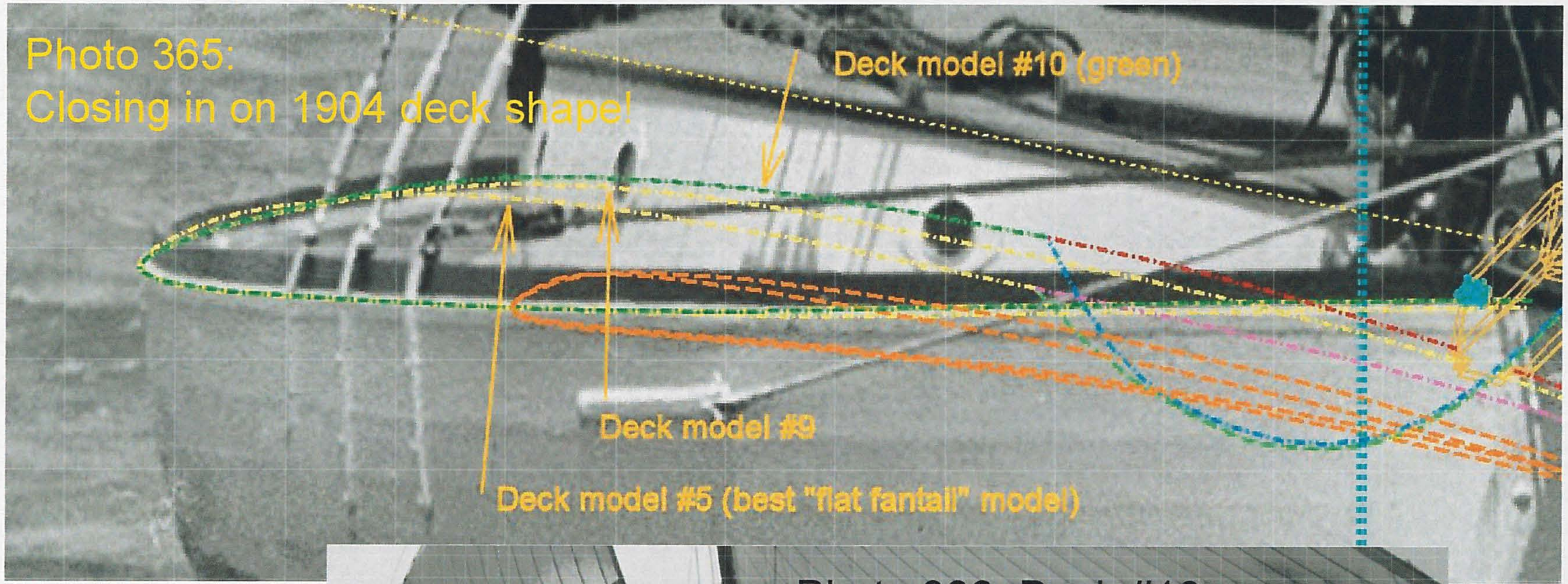


Photo 365:
Closing in on 1904 deck shape!

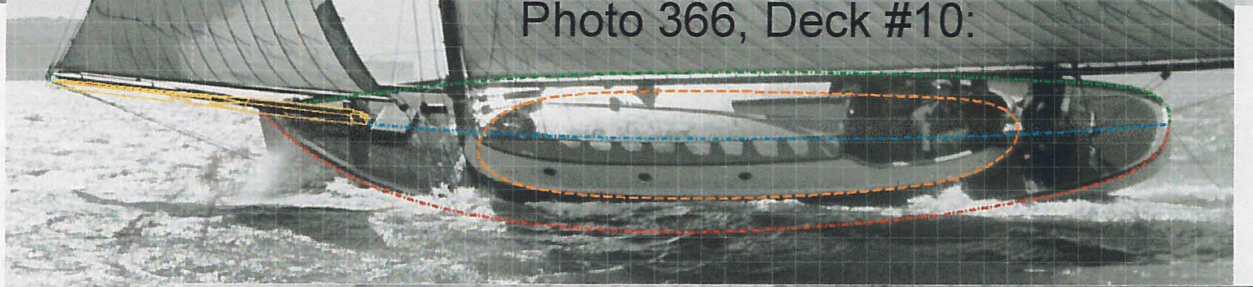


Photo 366, Deck #10:

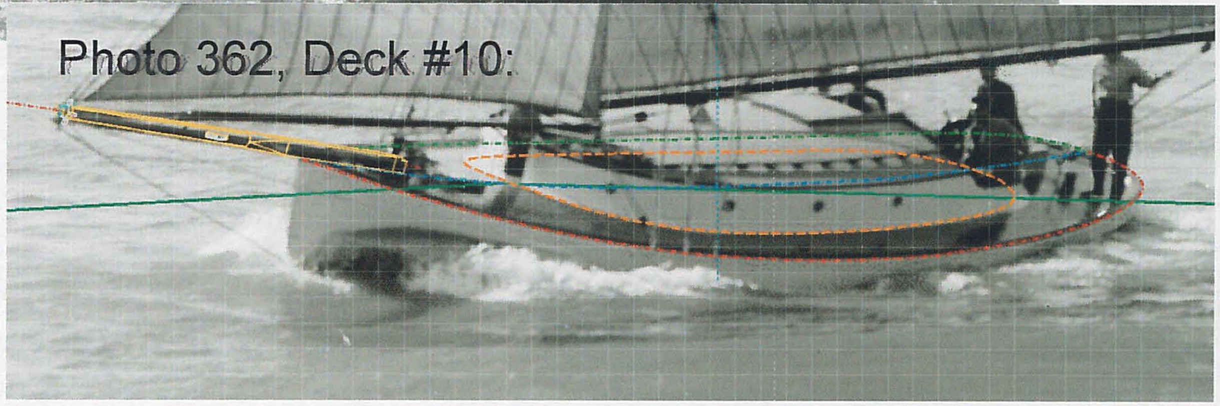
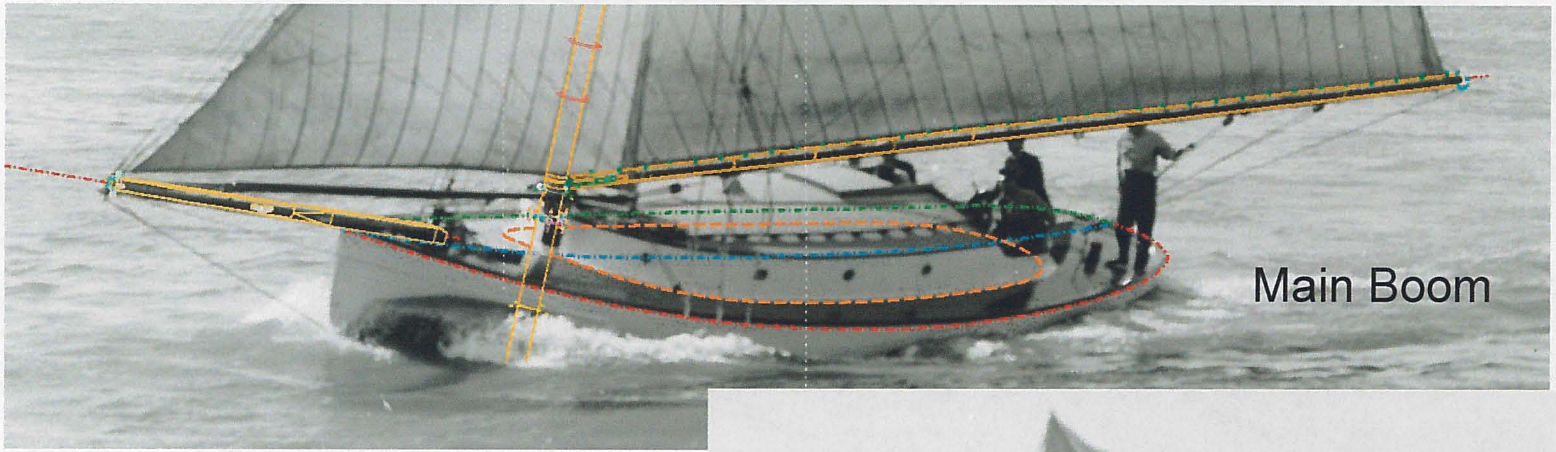


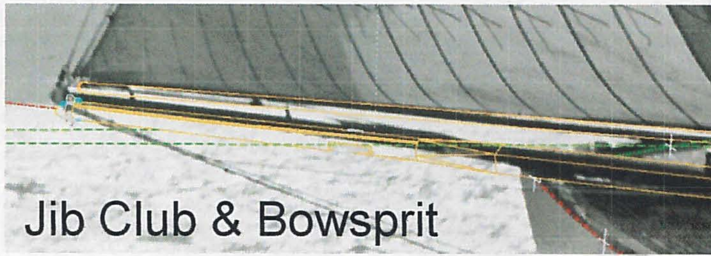
Photo 362, Deck #10:

Close agreement
between 3D model
and historic photos
after 130+ trials:

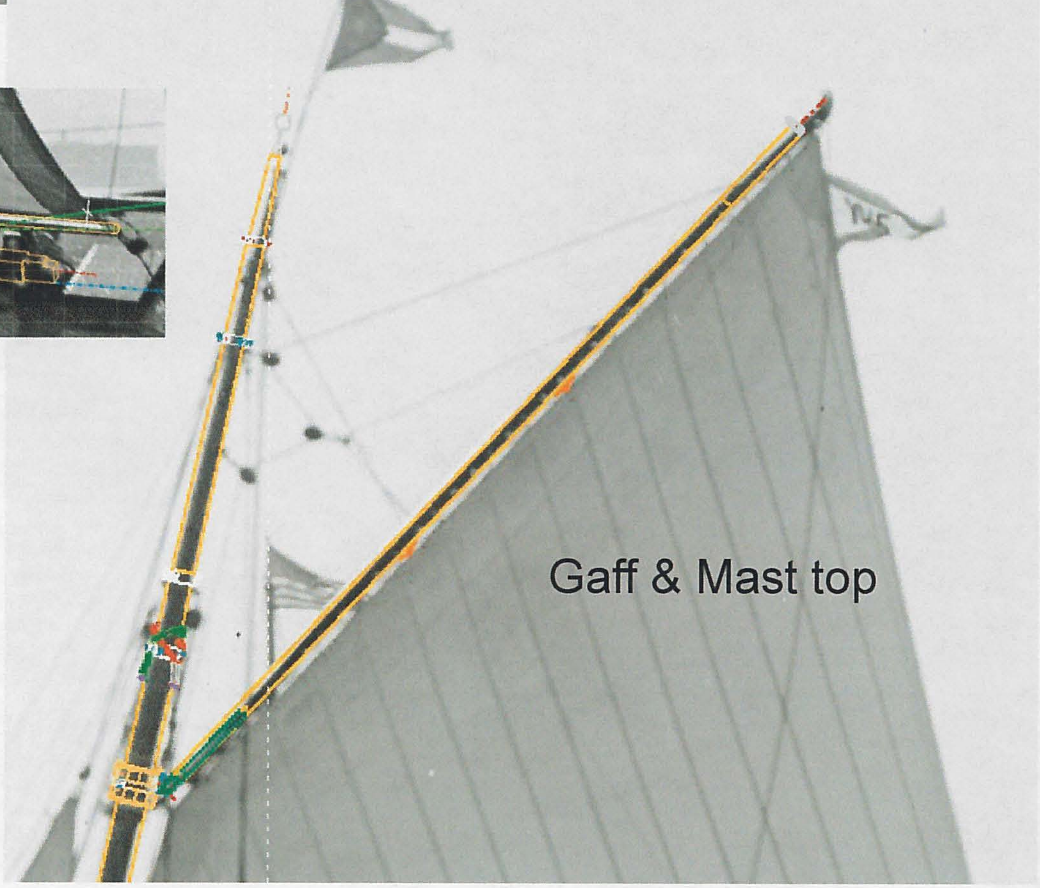
Historic Spar Study:



Main Boom

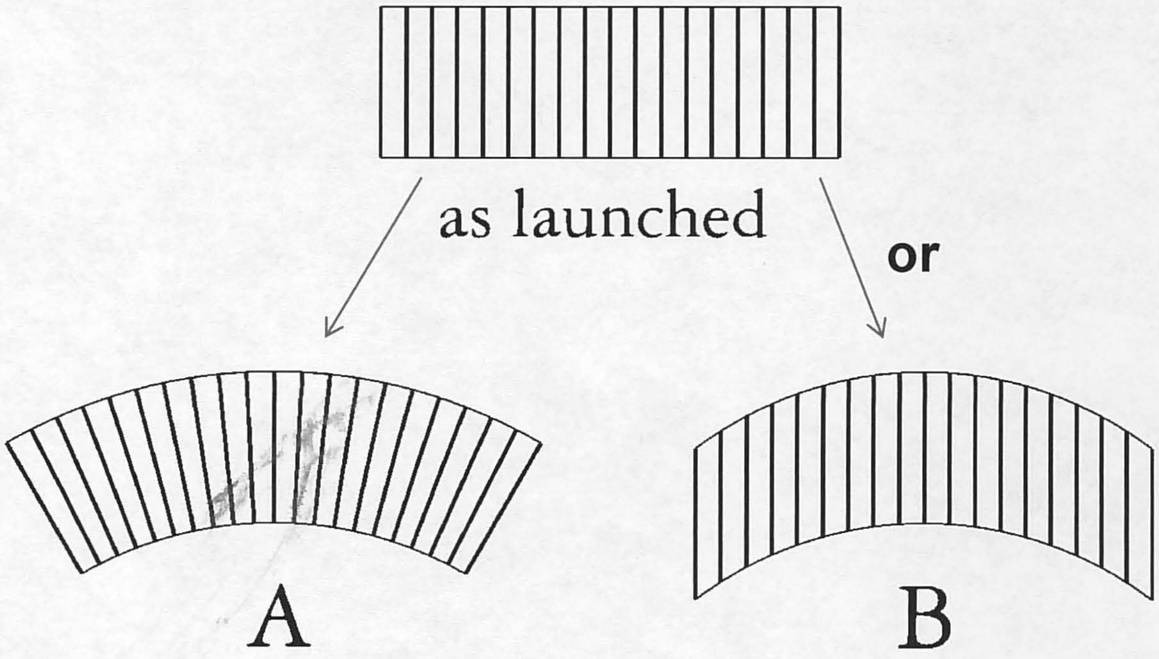


Jib Club & Bowsprit

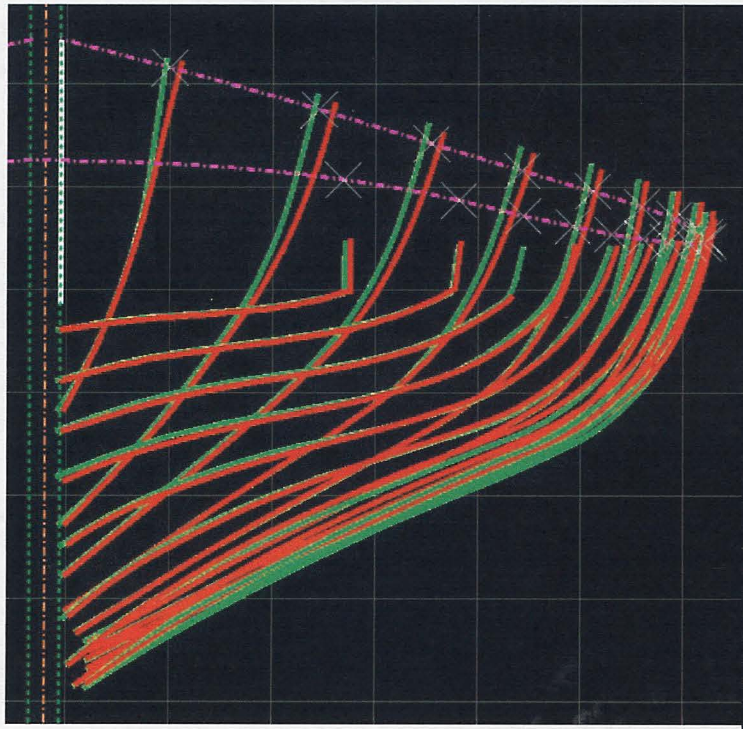


Gaff & Mast top

Now that the original deck sheer is mostly settled, the next question is how to back the hog out of the hull itself. What happens to sections of a hull as it hogs? What distortions occur?

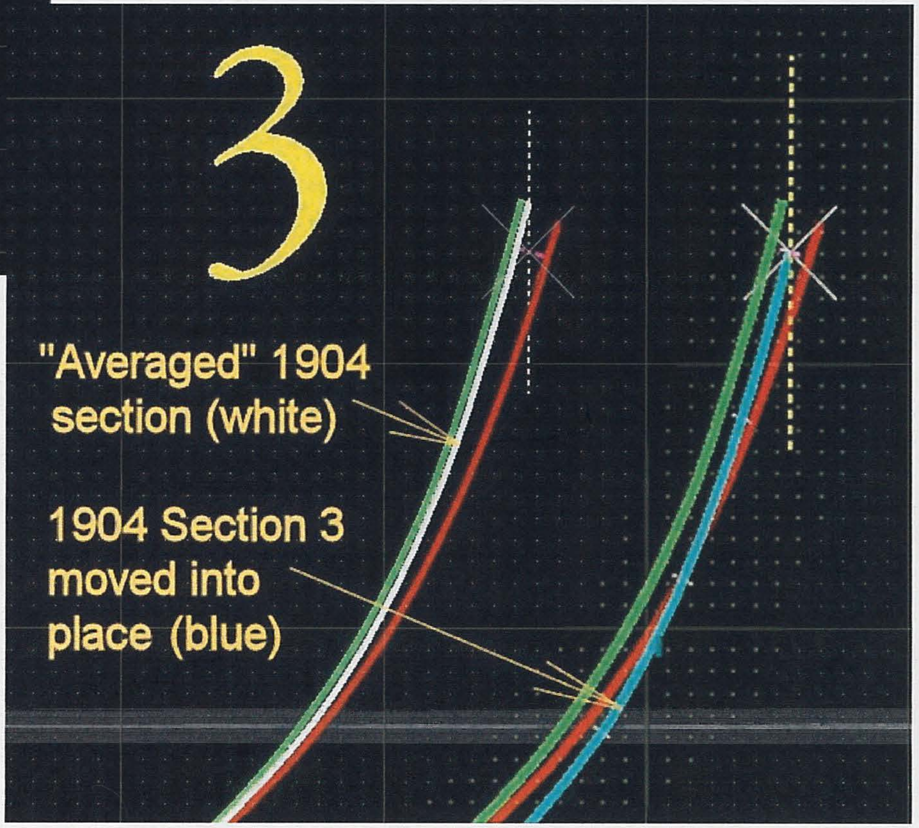


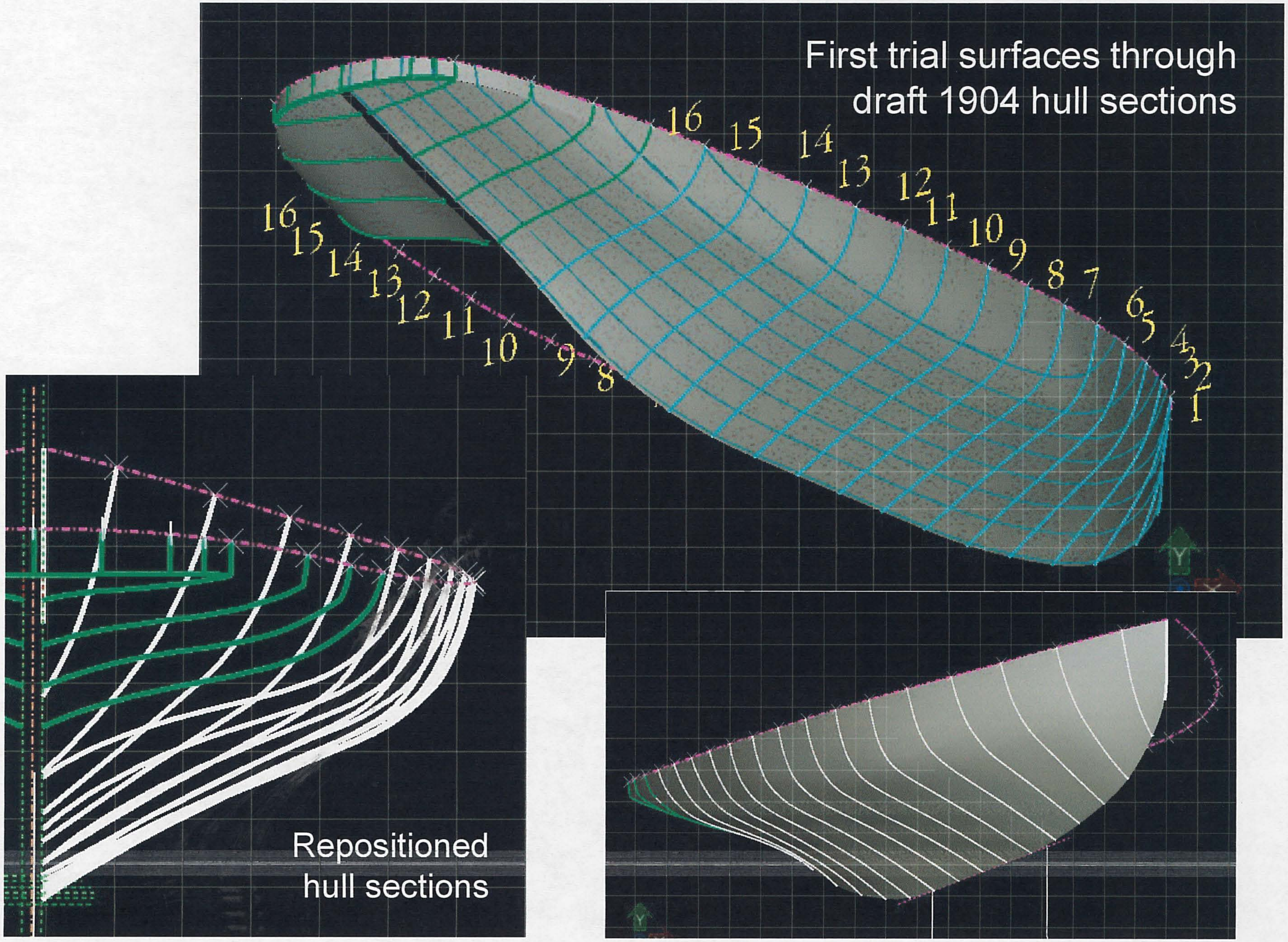
B seems most likely, since A would require the main deck and sheer plank to stretch, or the keel to compress, or both.



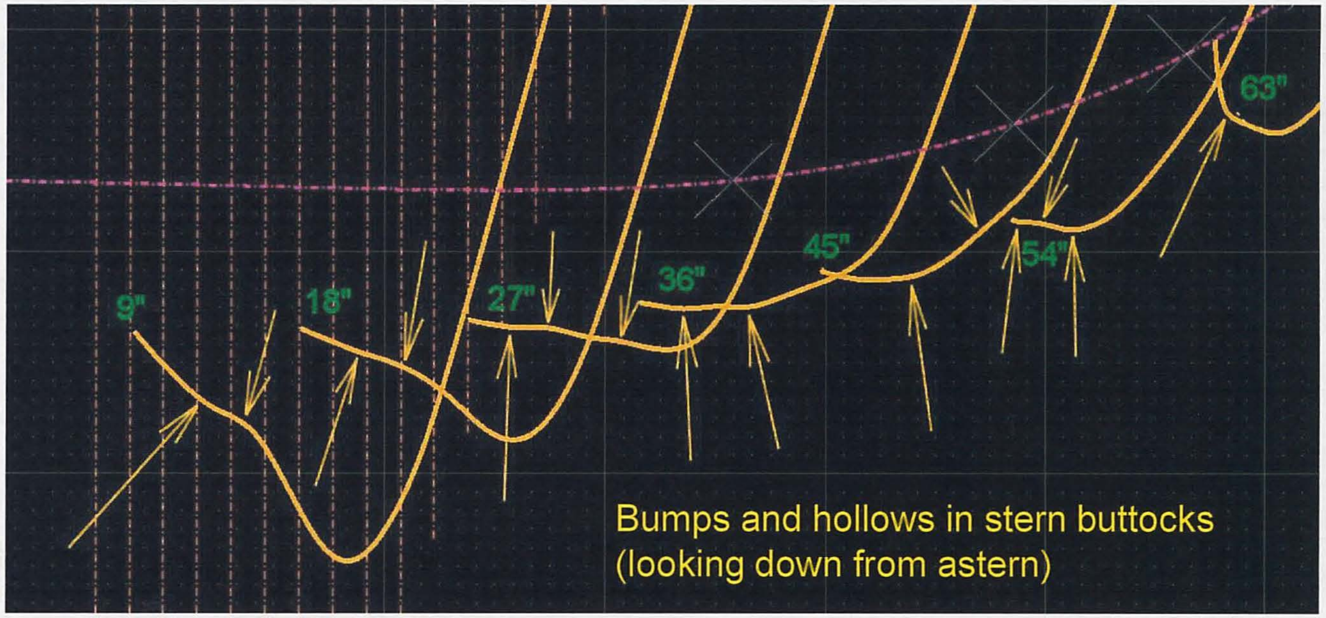
P&S sections of 2012 hull, taken in planes spaced every two feet, Mirrored port to starboard for comparison, along with 1904 sheer (top of 1904 sheer plank).

I drew “averaged” sections, then moved them till their tops rested on the crosses at the sheer plank (dashed purple line above)

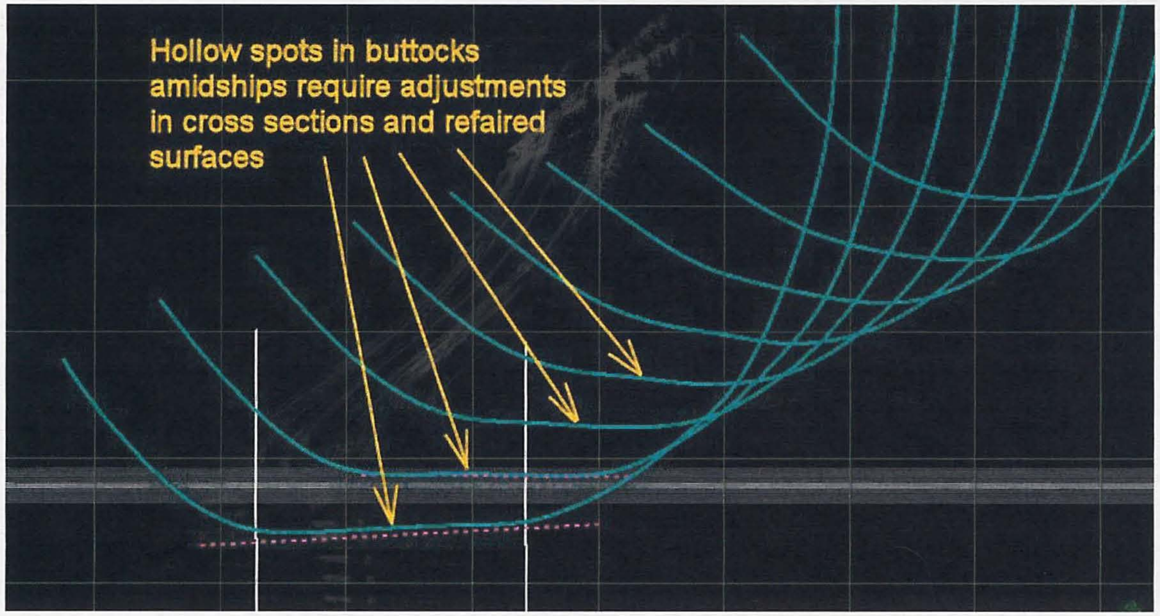

3
"Averaged" 1904 section (white)
1904 Section 3 moved into place (blue)


First trial surfaces through
draft 1904 hull sections
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
16
15
14
13
12
11
10
9
8
Y
Repositioned
hull sections
Y

Several rounds needed to remove unfair spots and resurface new sections:

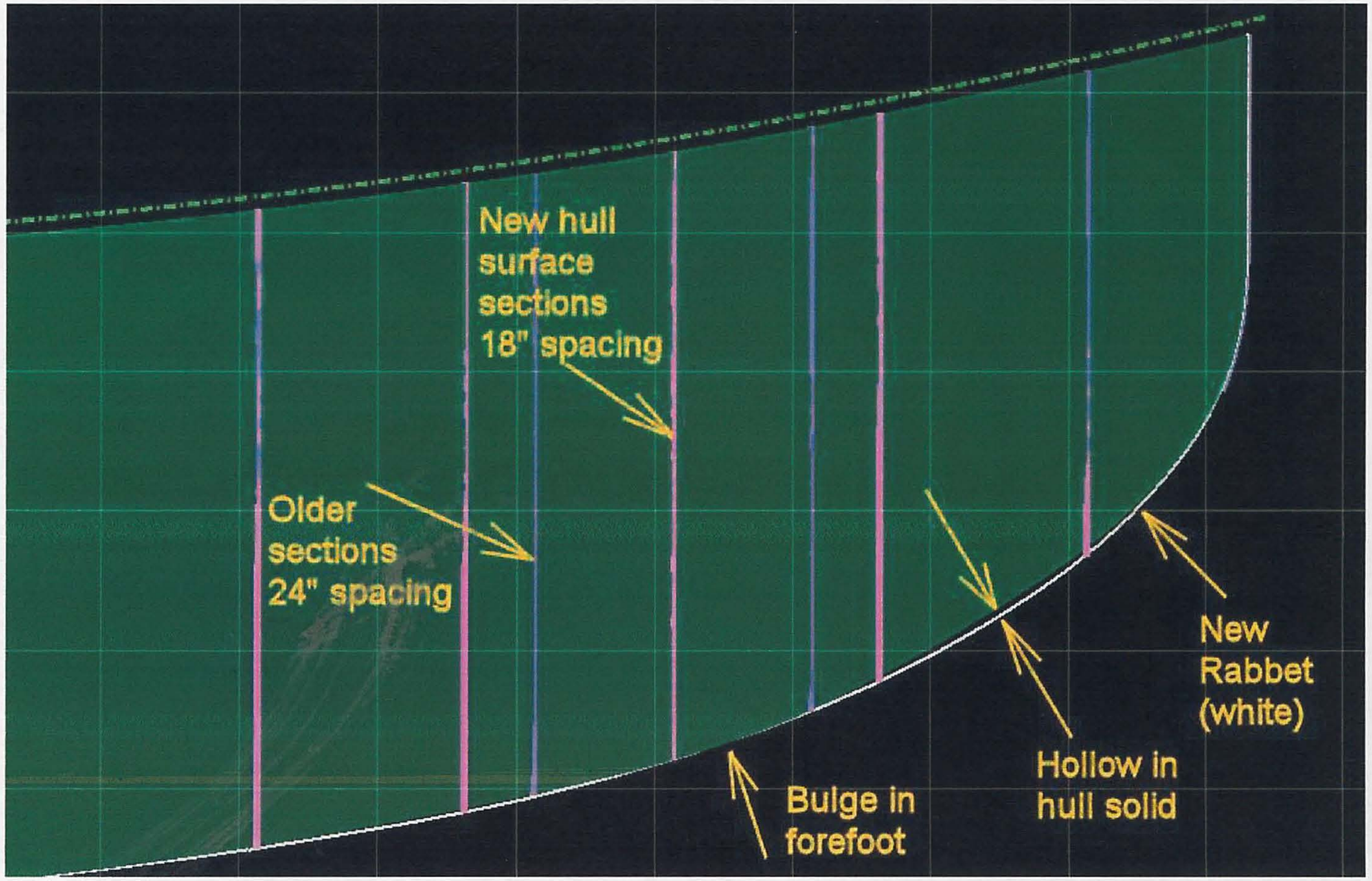


Bumps and hollows in stern buttocks
(looking down from astern)

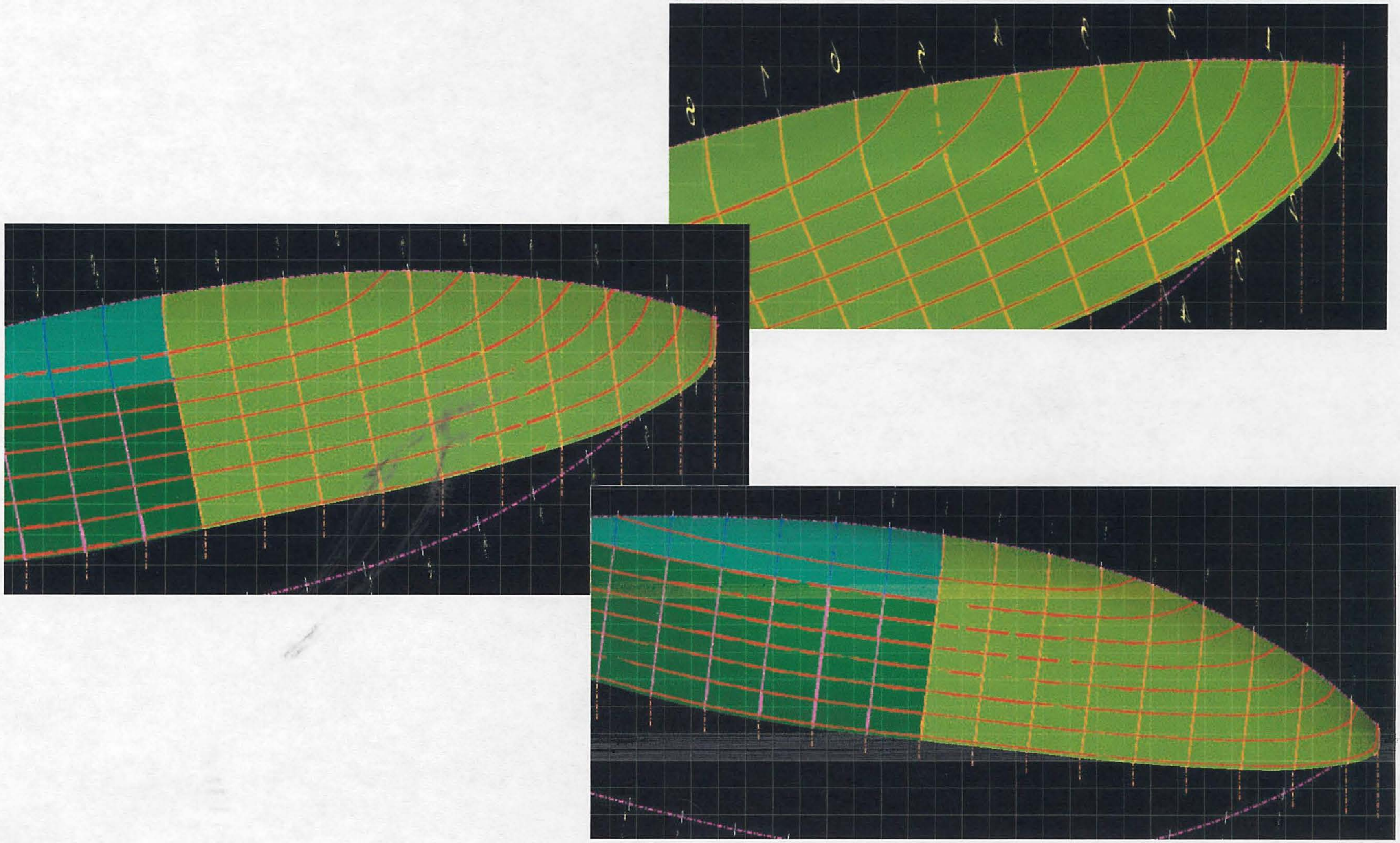


Hollow spots in buttocks
amidships require adjustments
in cross sections and refaired
surfaces

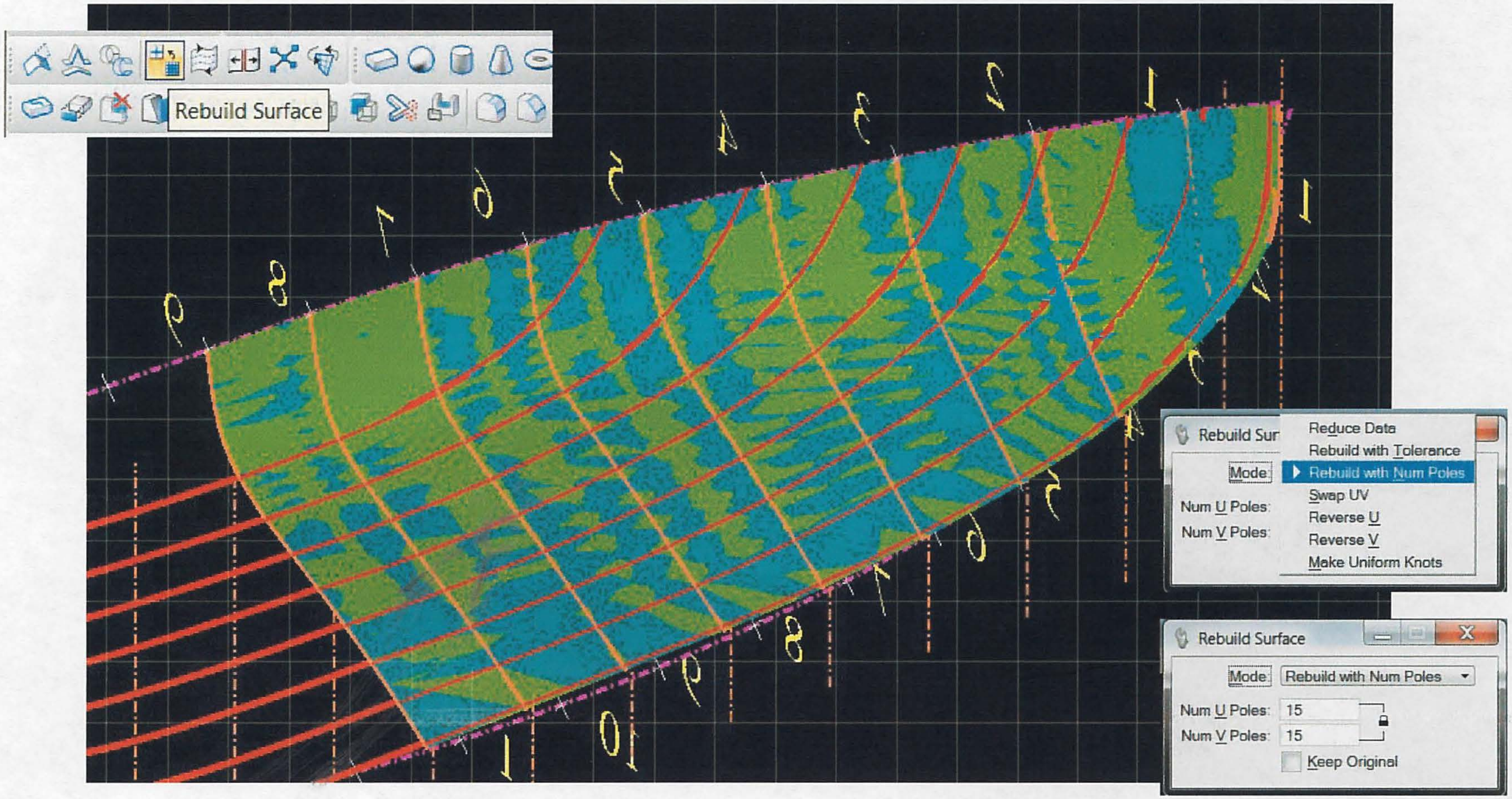
Some “fixes” require extra sections and some experimentation:



Aside from examining buttocks and sections in detail, another test for fairness is the “shine” test – observing how light reflects from the CAD surface of the hull as a way to spot problems.



A third test for fairness in 3D CAD is whether a hull surface will "thicken" into a solid for planking. If not, it must be "rebuilt."



Rebuild Surface

Mode: Rebuild with Num Poles

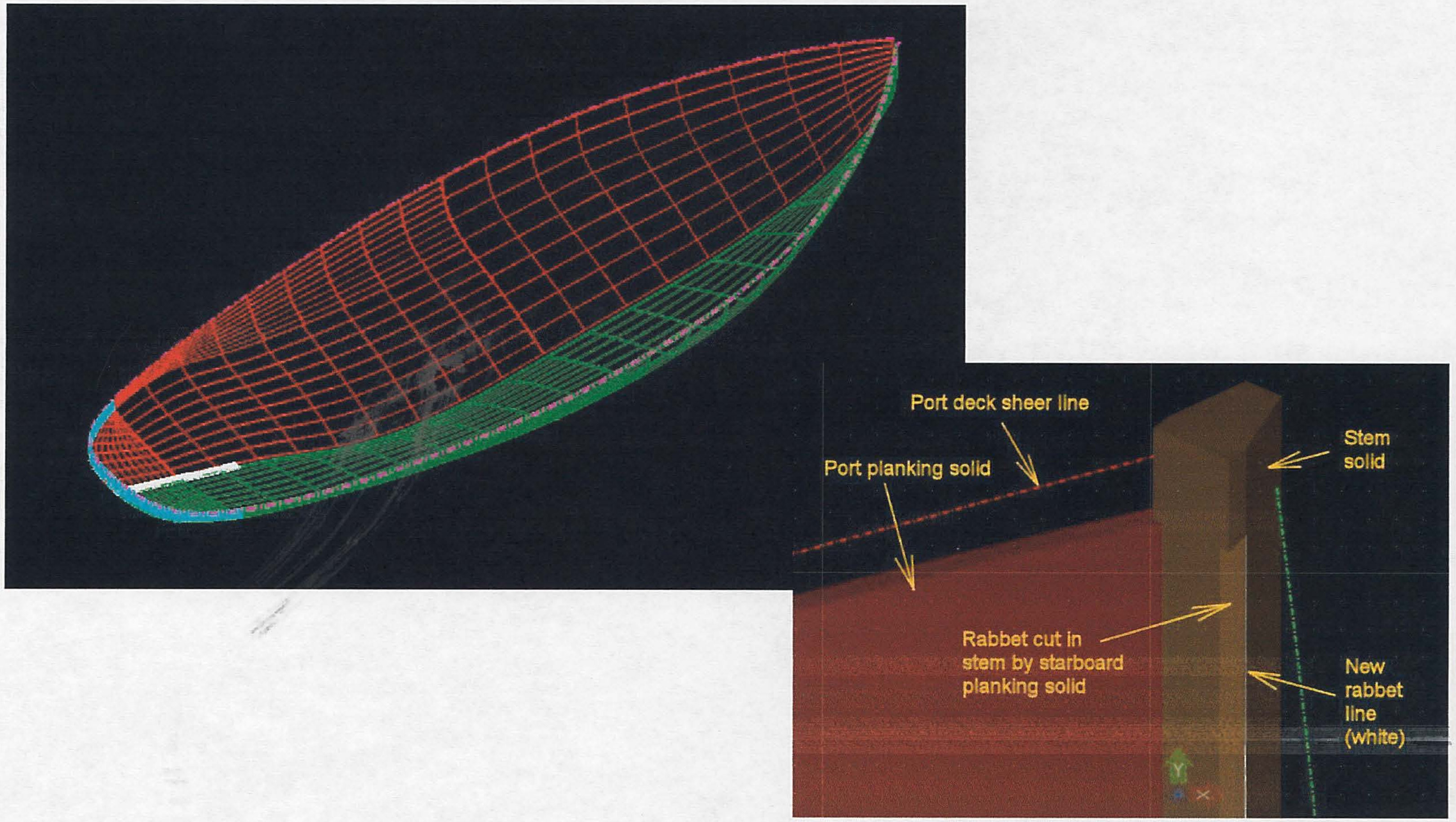
Num U Poles: 15

Num V Poles: 15

☐ Keep Original

"Rebuilding" is a mathematical procedure that irons out hidden "kinks." The rebuilt surface (15-node) is shown in blue, unrebuilt in green. The superposition shows the slightest changes, which in this case are tiny fractions of an inch.

Once a fair “restored” 1904 hull surface is generated, a second surface can be offset to outside of frames (for a set of lines) and third surface to outside of ceiling planking. The hull surface can also be thickened to a 1” thick solid for planking, so work on other structural elements can proceed (frames, stem, keel)



Before a set of “restored” lines can be drawn, the floating water line (FWL) must be established. The scum line on *Kathleen*’s hull in 2012 permitted the calculation of her displacement (23,560 pounds) by creating a solid in the CAD file that represented “the hole in the water” that the hull filled, and multiplying the volume by the density of salt water. Arriving at her 1904 displacement required subtracting the weight of additions like fiberglass plywood hull sheathing, engine, ballast keel, fuel tanks, etc. then adding back in weights of centerboard and trunk, larger spars, sails, decking, etc.

The boot top in the Walter Scott photos became a key to Kathleen’s trim in 1904-1910, assuming that the top would have been painted parallel to her floating water line. This resulted in a slight change to the pitch of the 3D model and a new set of sections and water lines.

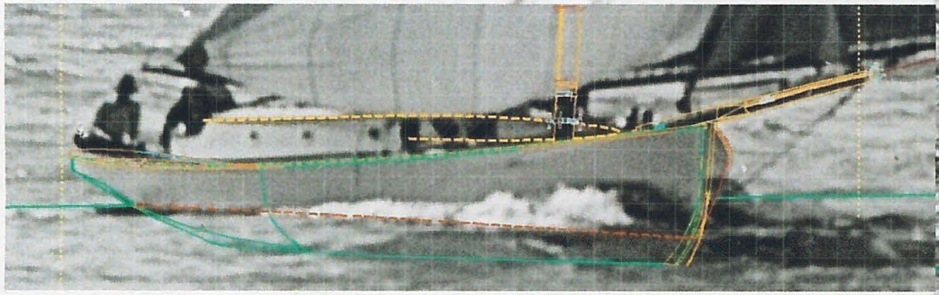


Photo 363

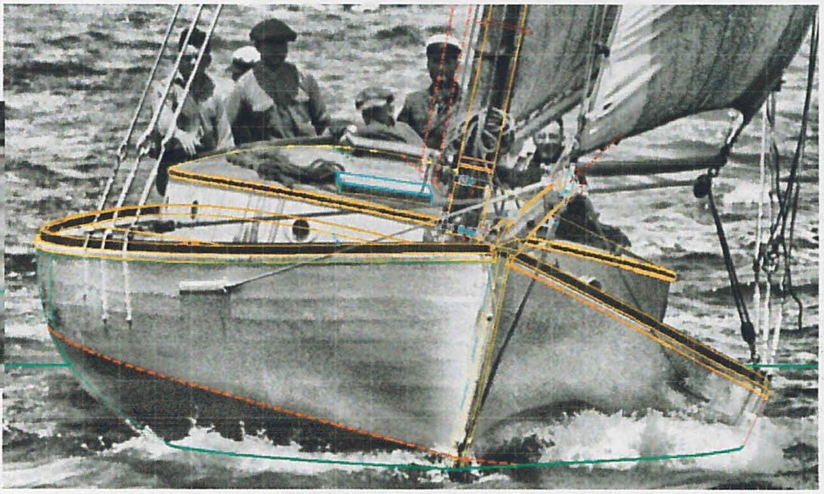
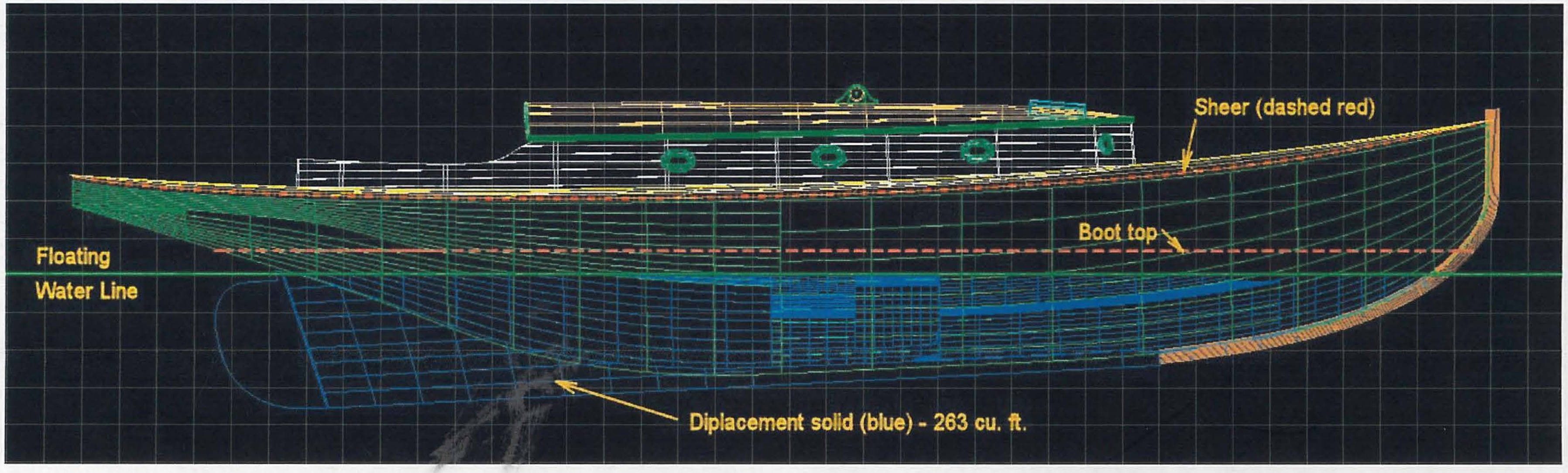


Photo 365

Kathleen's 1904 displacement was calculated to be about 16,850 pounds. The displacement solid was trimmed parallel to the boot top to the volume of about 262.6 cubic feet, assuming a density for cold salt water of 64.2 lbs/cu. ft.



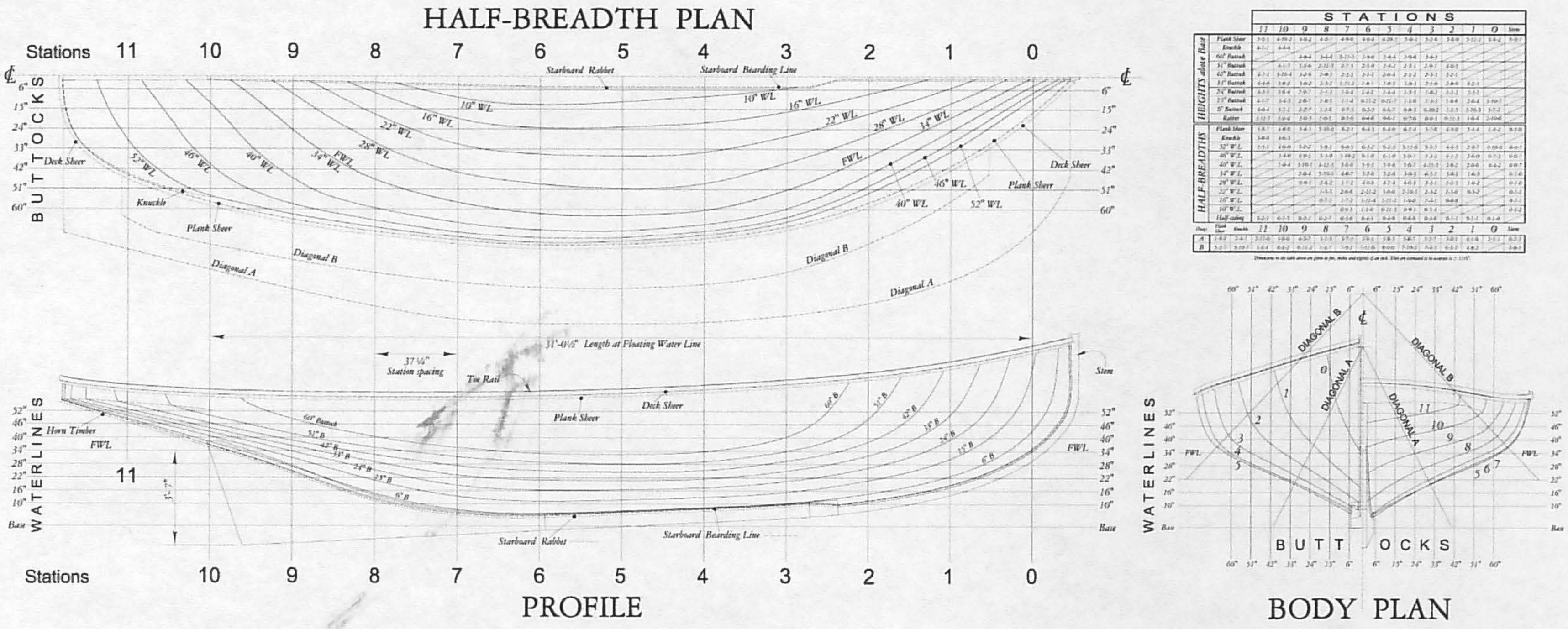
The top of the displacement solid is the 1904 floating water line.

This being determined, a set of restored 1904 lines can be generated.

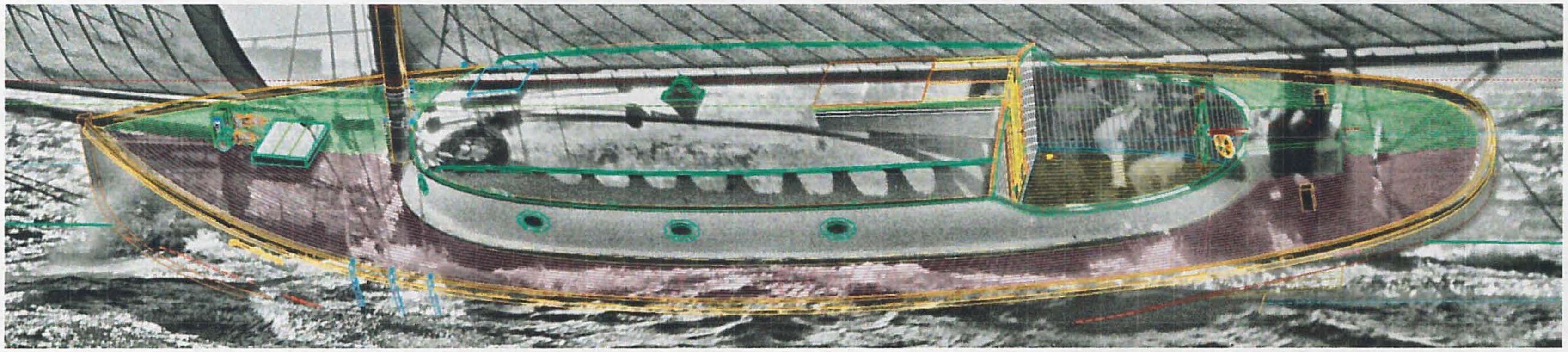
Lines to outside of frames (1” scale on 34”x66” sheet)

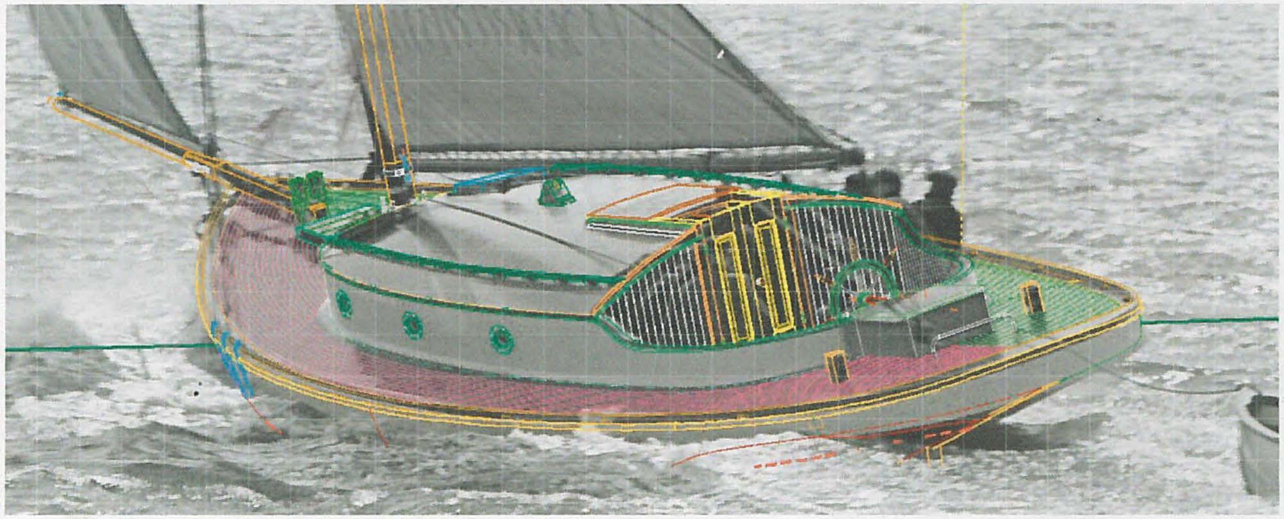
SLOOP YACHT

KATHLEEN

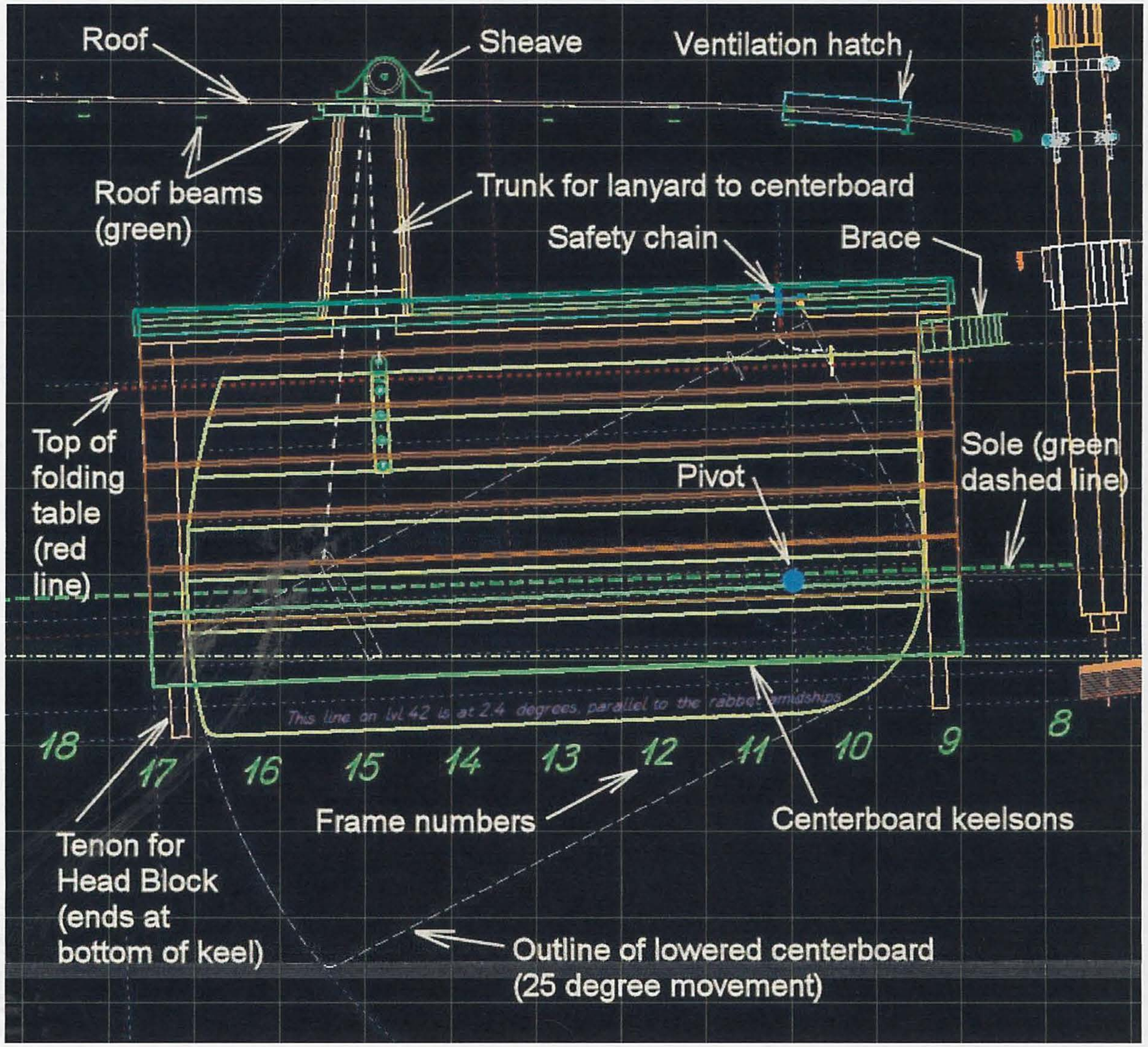


As the 3D “restored” model of Kathleen has progressed, projections of parts of the model to Walter Scott’s photos 366, 362, 360 and 365 have Been used to locate, proportion and scale various parts such as cabin roof, cockpit companionway, sprung decking, hatches and fittings.

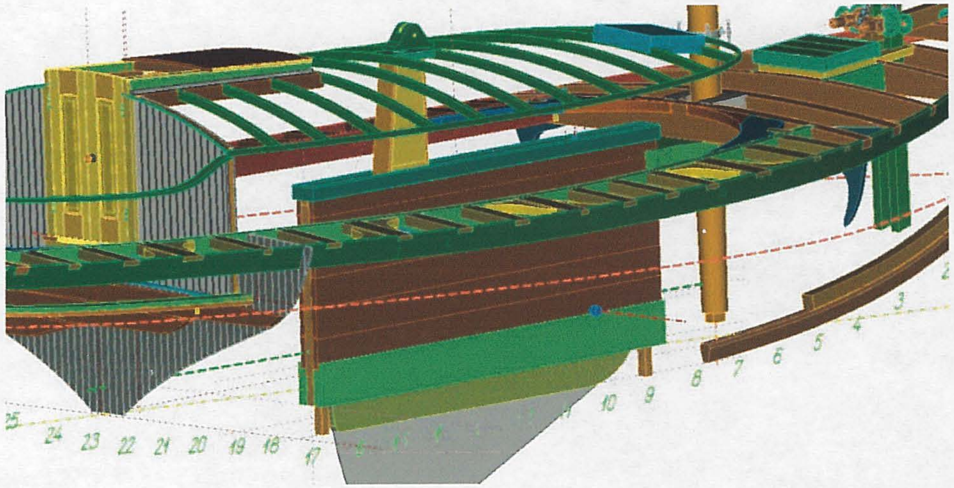


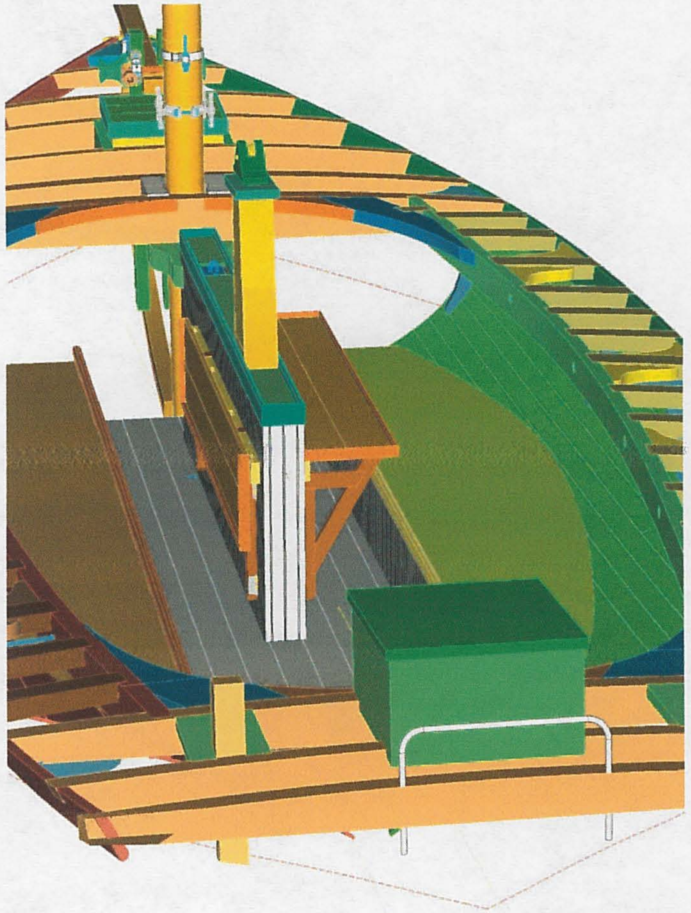


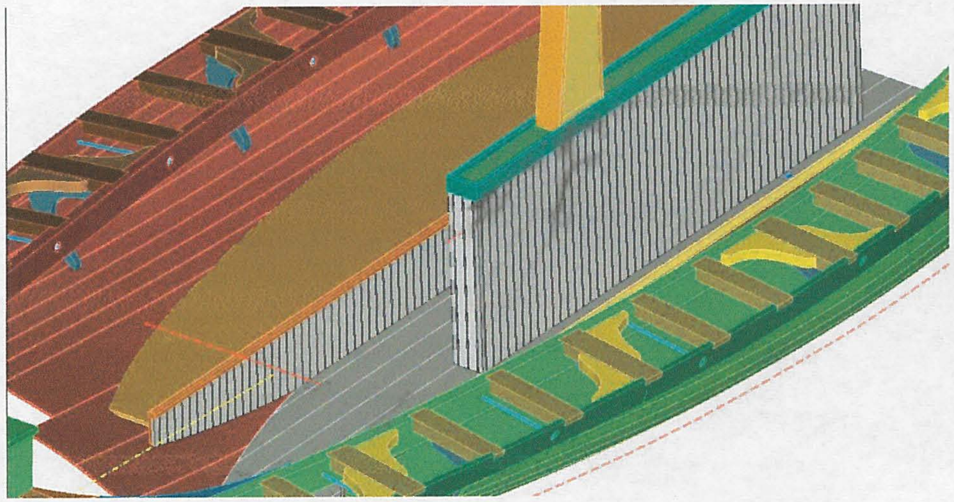
Restored centerboard details based primarily on H.I. Chappelle data and *Kathleen*'s 8'-9" centerboard slot remains in 2012 :


Roof
Sheave
Ventilation hatch
Roof beams (green)
Trunk for lanyard to centerboard
Safety chain
Brace
Top of folding table (red line)
Sole (green dashed line)
Pivot
This line on lvl 42 is at 2.4 degrees, parallel to the rabbet amidships
18
17
16
15
14
13
12
11
10
9
8
Frame numbers
Centerboard keelsons
Tenon for Head Block (ends at bottom of keel)
Outline of lowered centerboard (25 degree movement)

Some details of cabin interior and centerboard trunk finish



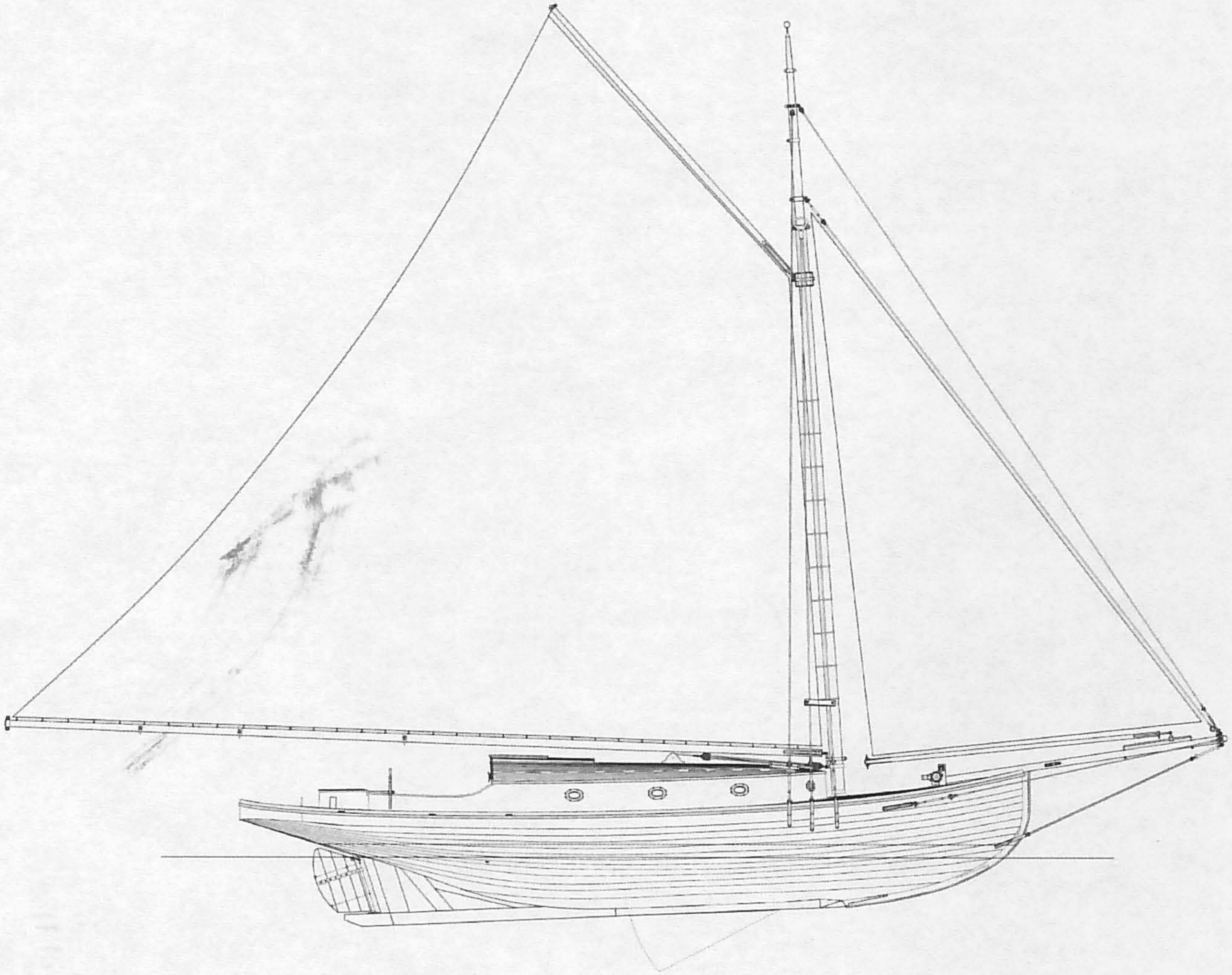




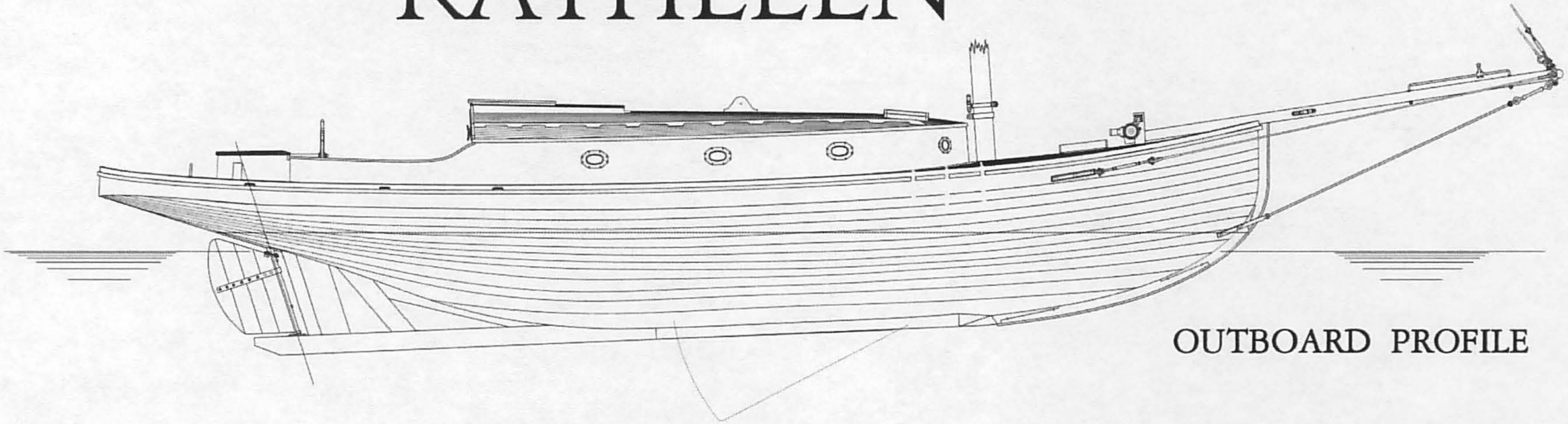
SLOOP YACHT

KATHLEEN

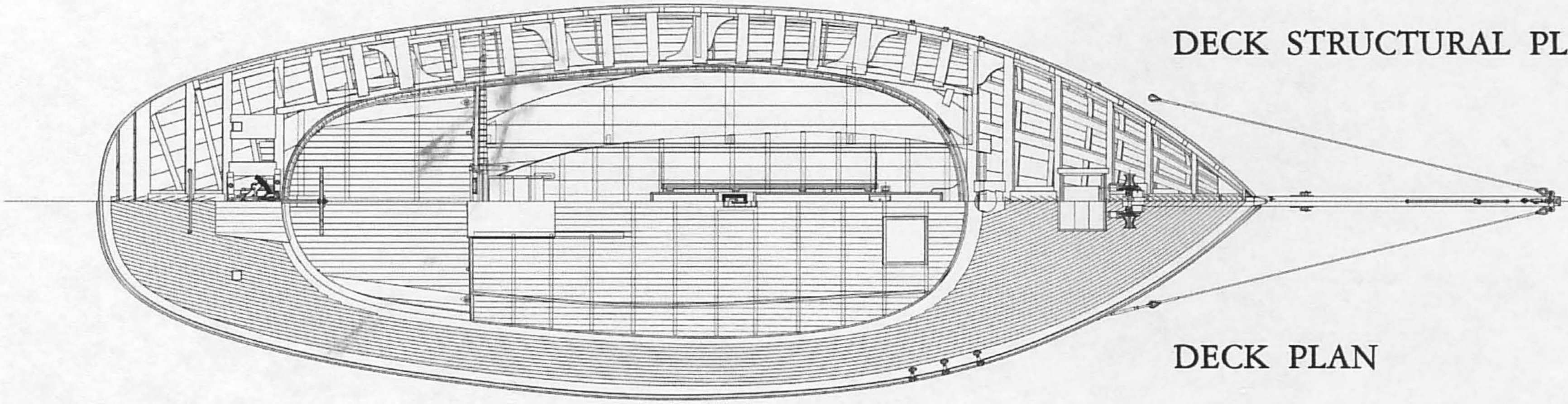
1904



SLOOP YACHT
KATHLEEN



OUTBOARD PROFILE

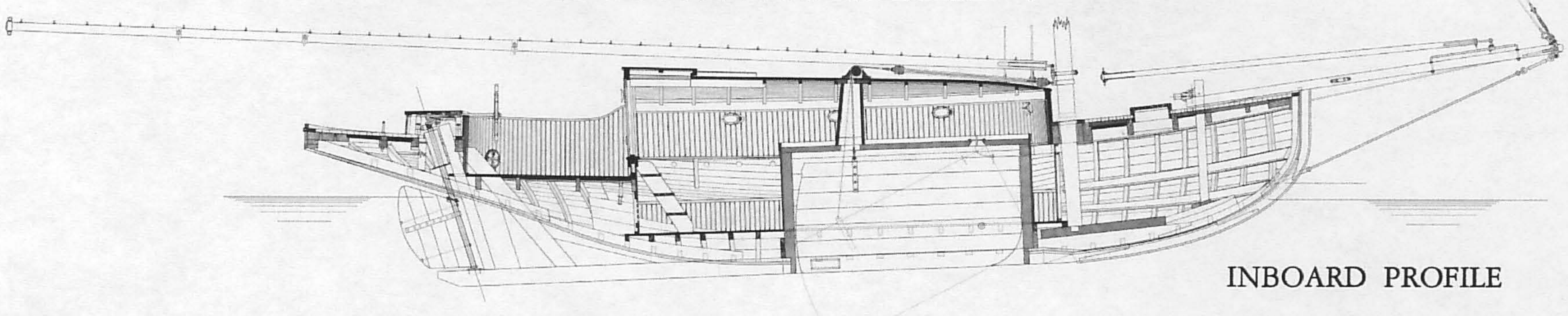


DECK STRUCTURAL PLAN

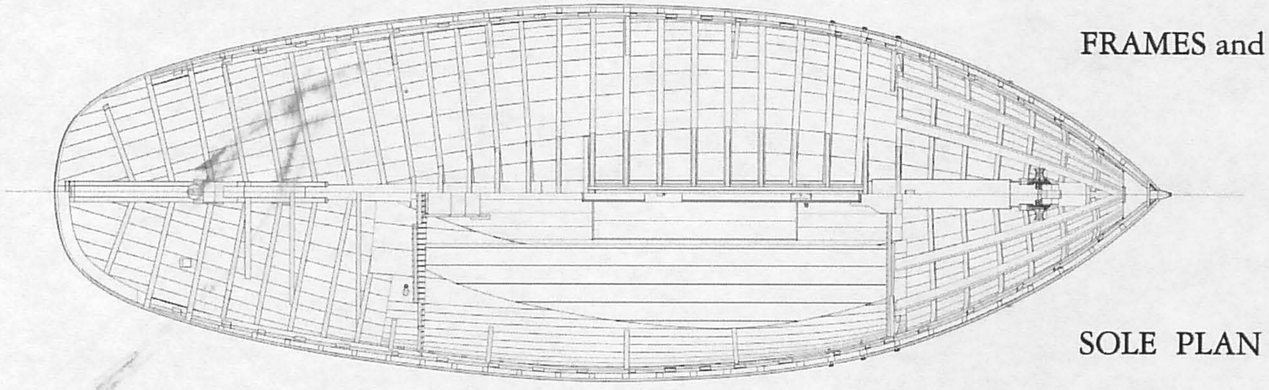
DECK PLAN

SLOOP YACHT

KATHLEEN

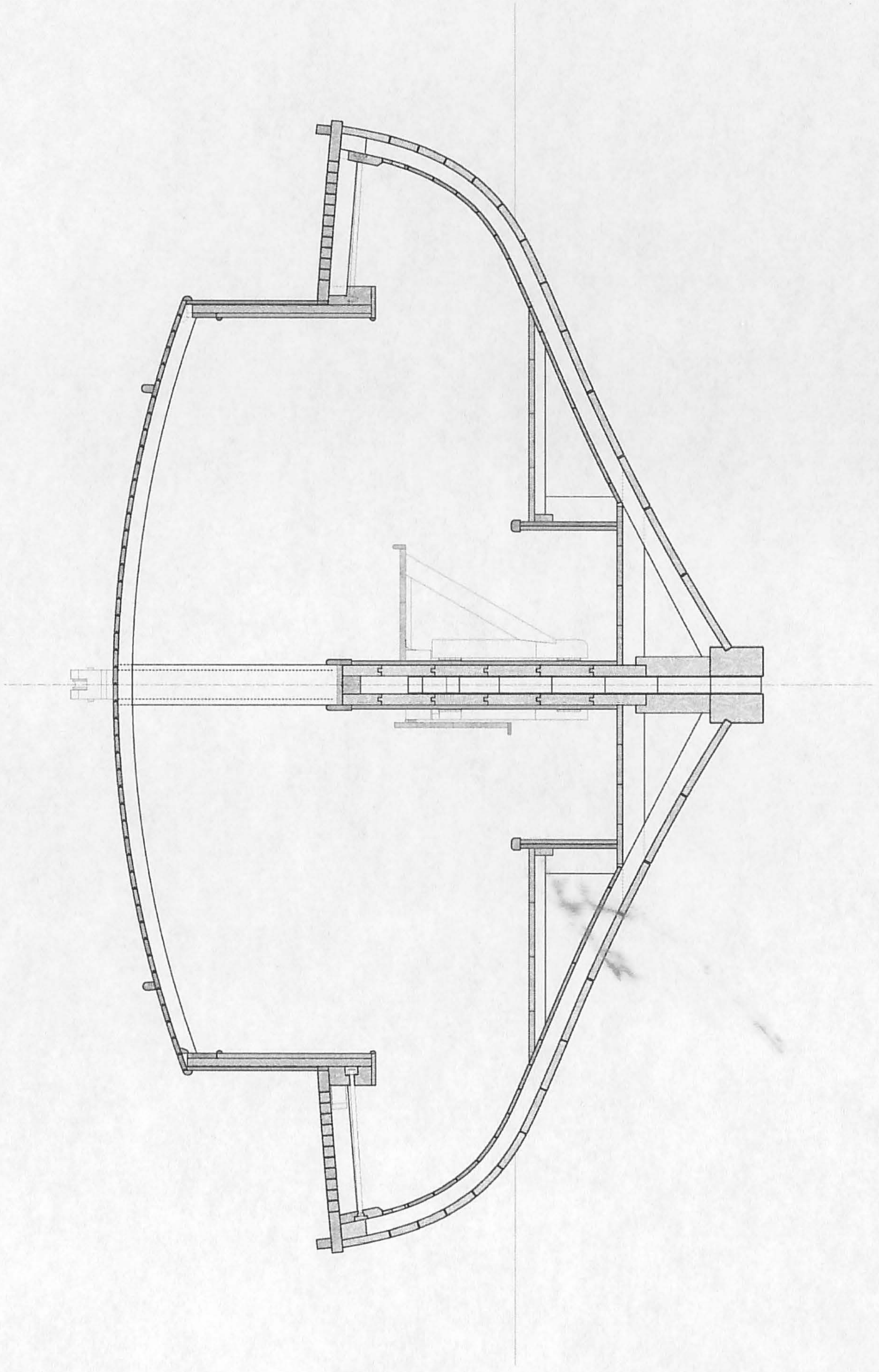


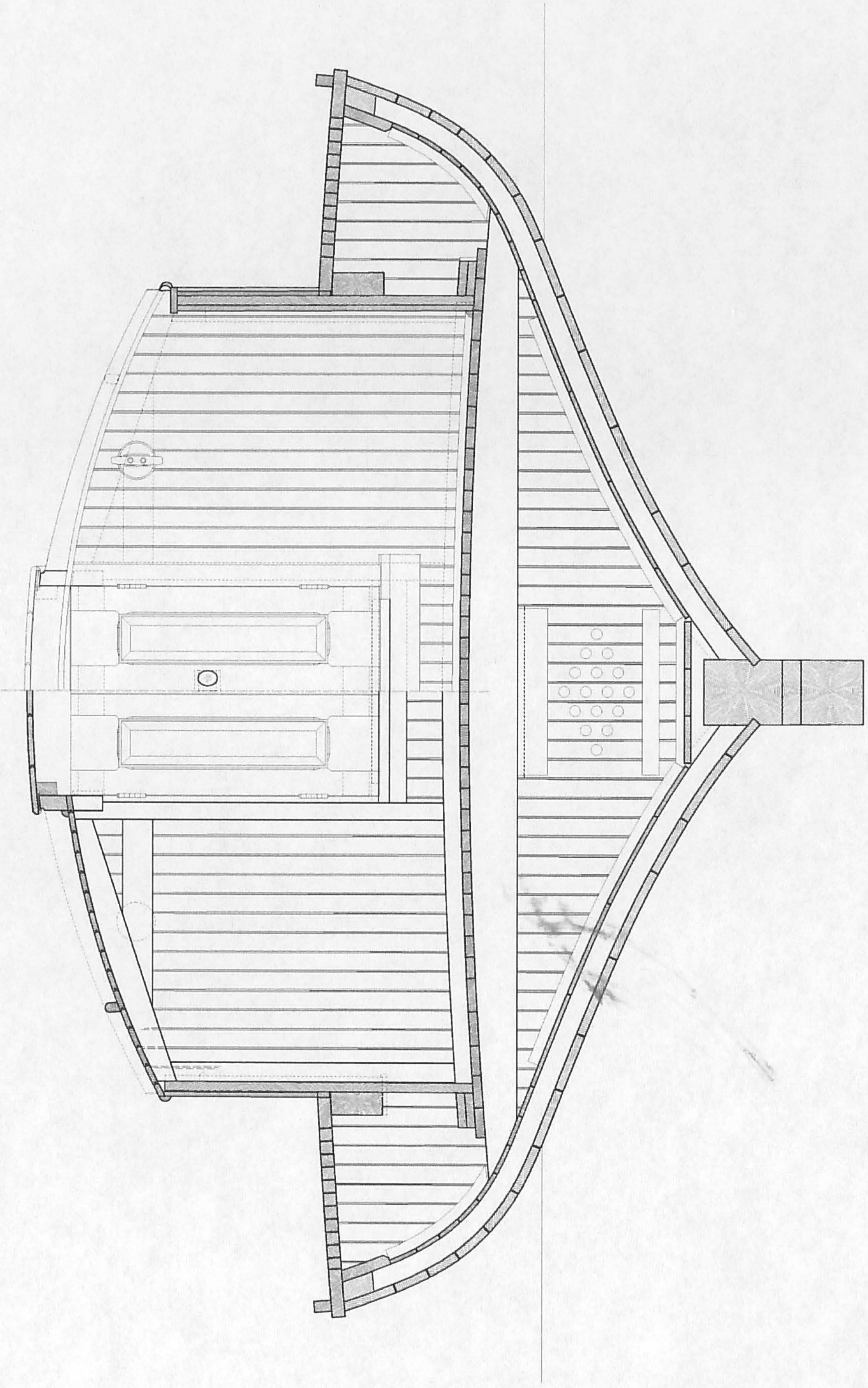
INBOARD PROFILE



FRAMES and PLANKING

SOLE PLAN



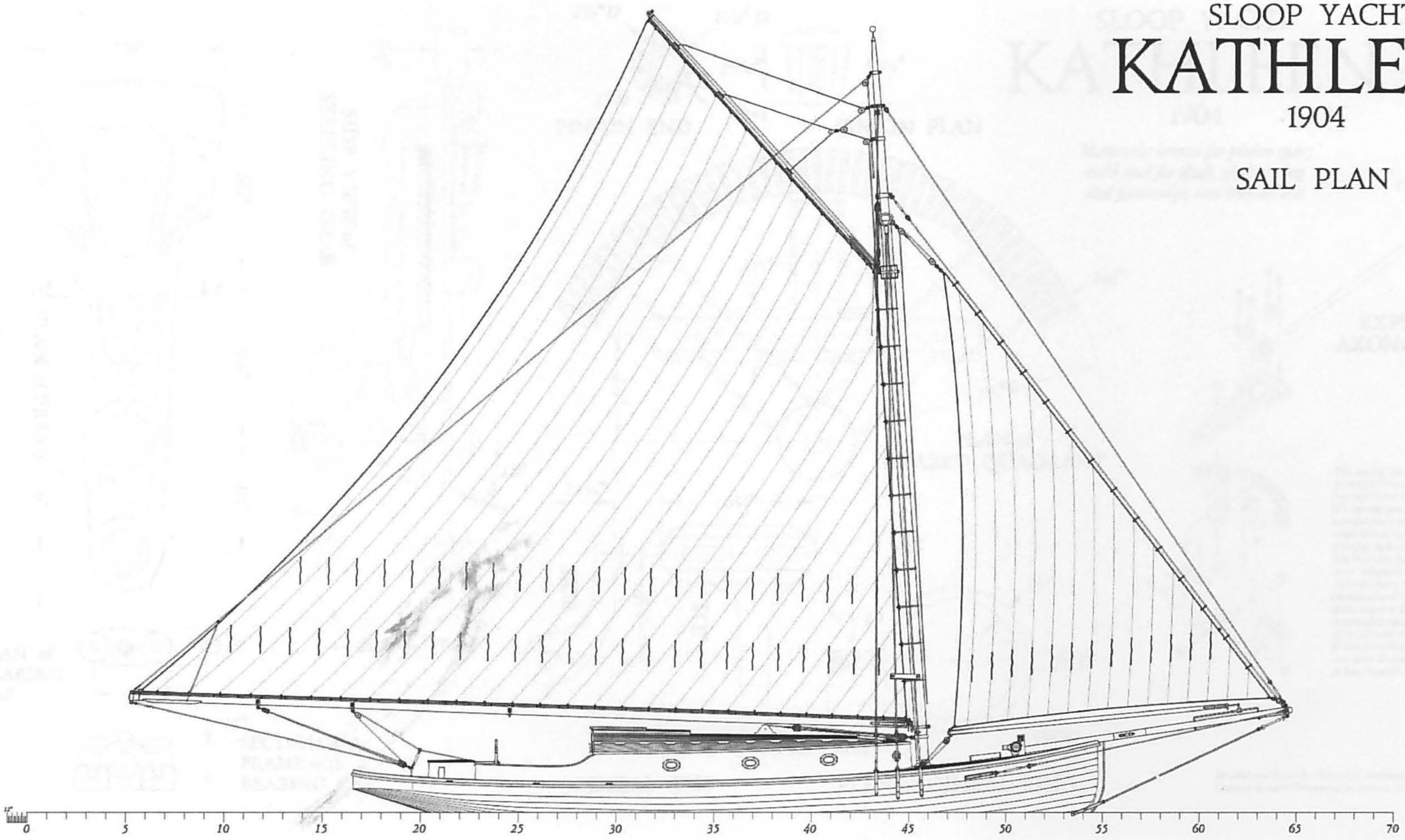


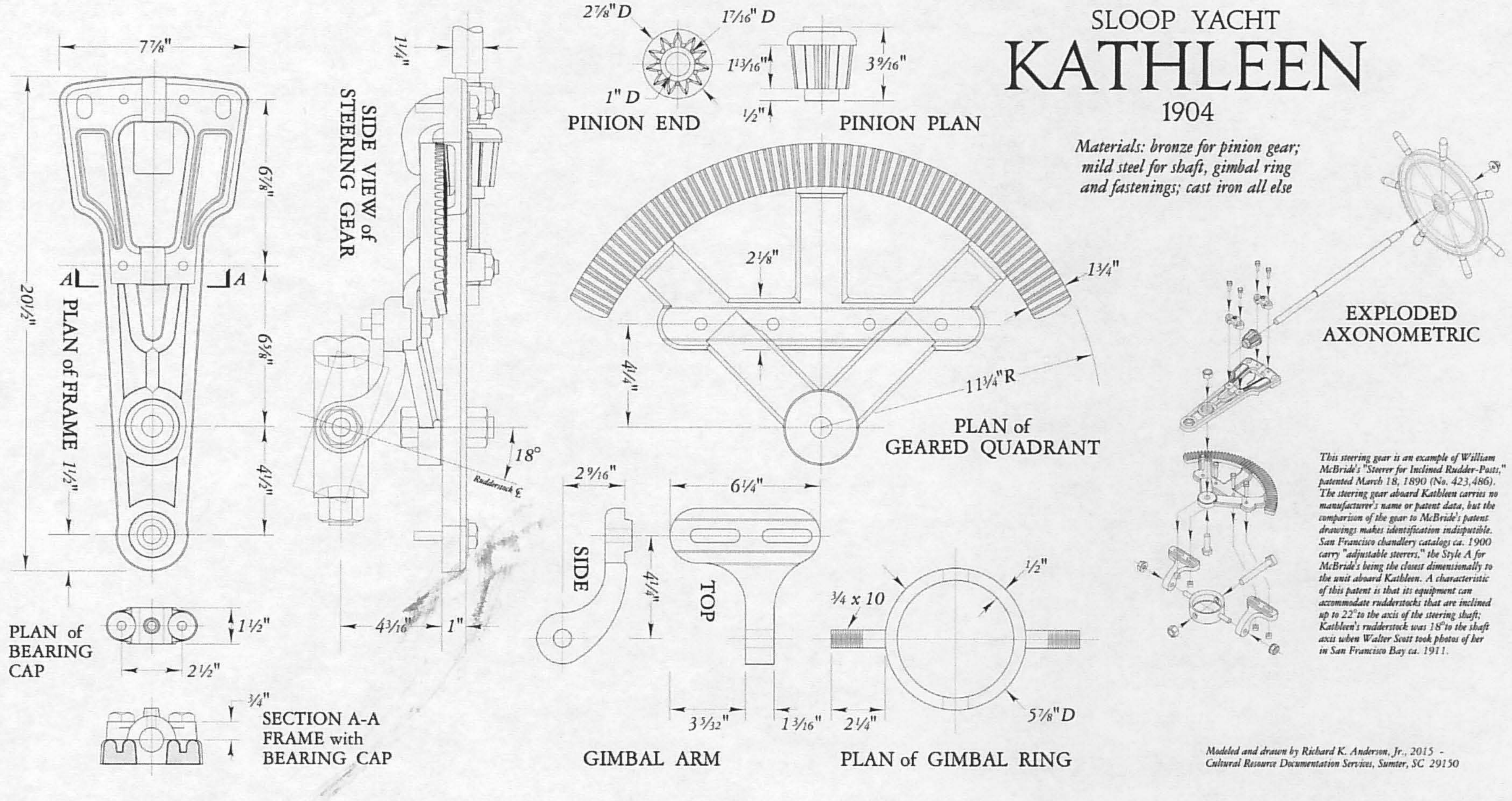
SLOOP YACHT

KATHLEEN

1904

SAIL PLAN





SLOOP YACHT

KATHLEEN

1904

Materials: bronze for pinion gear;
mild steel for shaft, gimbal ring
and fastenings; cast iron all else

This steering gear is an example of William McBride's "Steerer for Inclined Rudder-Posts," patented March 18, 1890 (No. 423,486). The steering gear aboard Kathleen carries no manufacturer's name or patent data, but the comparison of the gear to McBride's patent drawings makes identification indisputible. San Francisco chandlery catalogs ca. 1900 carry "adjustable steerers," the Style A for McBride's being the closest dimensionally to the unit aboard Kathleen. A characteristic of this patent is that its equipment can accommodate rudderstocks that are inclined up to 22° to the axis of the steering shaft; Kathleen's rudderstock was 18° to the shaft axis when Walter Scott took photos of her in San Francisco Bay ca. 1911.

Modeled and drawn by Richard K. Anderson, Jr., 2015 -
Cultural Resource Documentation Services, Sumter, SC 29150

SLOOP YACHT

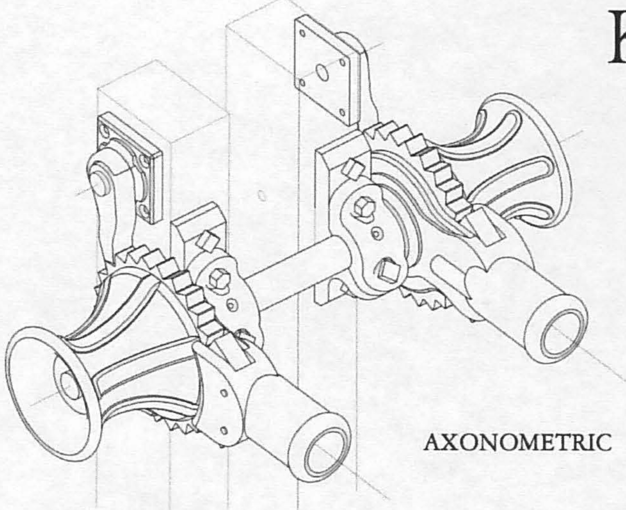
KATHLEEN

1904

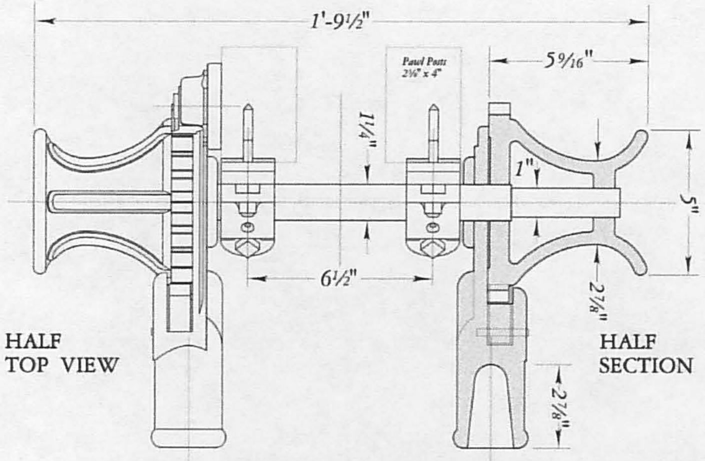
WINDLASS

Modeled and drawn by Richard K. Anderson, Jr., 2015
Cultural Resource Documentation Services, Sumter, SC 29150

Materials: cast iron for drums, bearings, and winding arms; mild steel for shaft, ratchet cams and fastenings

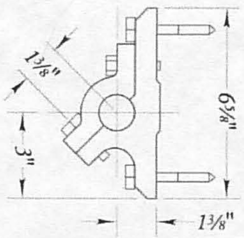


AXONOMETRIC

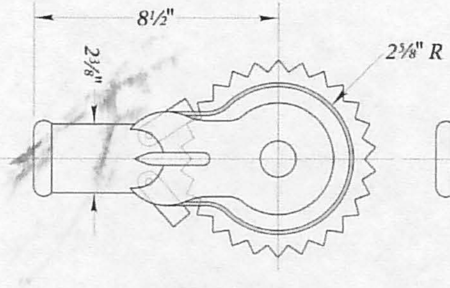


HALF TOP VIEW

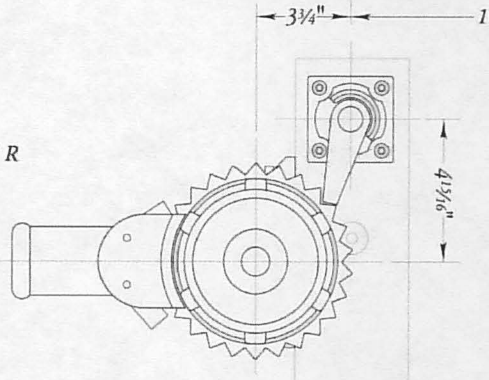
HALF SECTION



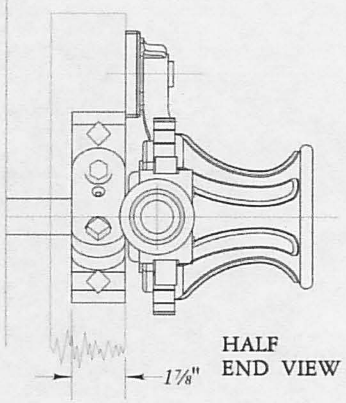
BEARING ELEVATION



WINDING ARM ELEVATION

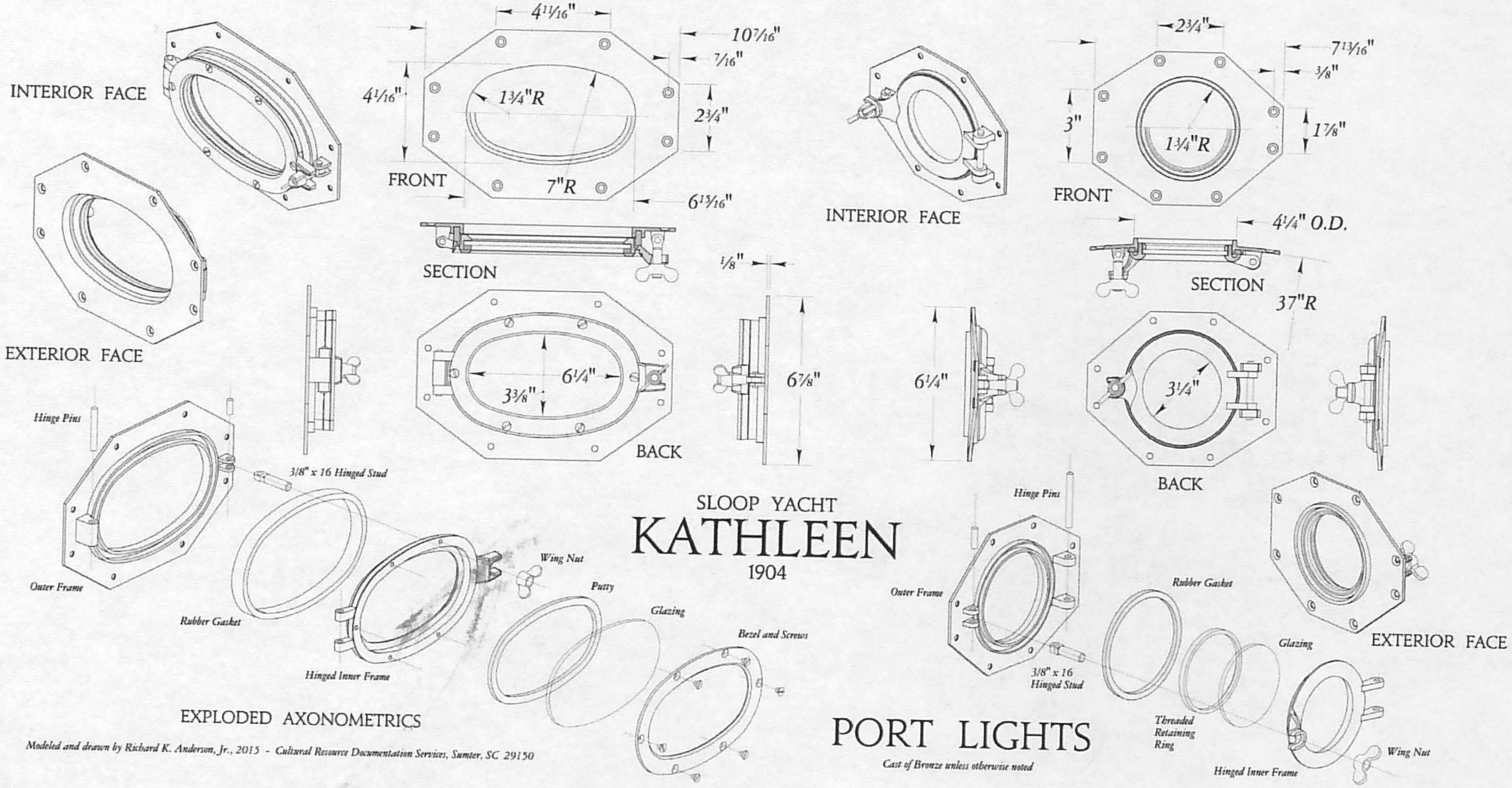


SIDE VIEW



HALF END VIEW

70



SLOOP YACHT
KATHLEEN
1904

PORT LIGHTS
Cast of Bronze unless otherwise noted

Modeled and drawn by Richard K. Anderson, Jr., 2015 - Cultural Resource Documentation Services, Sumter, SC 29150

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